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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY OF THE COMMON ROADS OF THE UNITED STATES

BY

NATHANIEL SOUTHGATE SHALER

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PREFATORY NOTE.

It is intended in the following memoir to set forth in a general way the facts which are known concerning the conditions of roadmaking in this country, so far as they are determined by its geologic and topographic features. In preparing the report the writer has availed himself of information obtained from a number of the officers of the Geological Survey, as well as from various persons who were not in that corps. He is particularly indebted to Maj. J. W. Powell, Prof. T. C. Chamberlin, Prof. C. R. Van Hise, Prof. J. E. Wolff, Mr. W. J. McGee, Mr. Frank Leverett, Mr. Bailey Willis, Mr. G. H. Eldridge, Mr. R. T. Hill, and Dr. J. W. Spencer, lately State geologist of Georgia. Some portion of the information here presented has been gathered by the Massachusetts Highway Commission, a board established by that Commonwealth, to which has been committed the task of a general inquiry concerning the roadbuilding materials which may be used by its people, as well as the business of constructing a system of State roads.

The detailed statement of this report concerning the location and value of road materials in this country could have been almost indefinitely extended by the use of census and other reports. This course has been avoided for the reason that the information thus obtained would have no value, except that of a statistical nature, and would be likely to mislead roadmasters in the choice of materials to be used in their work.

From the statements of this report it will readily be perceived that there is as yet but little trustworthy information in hand as to the relative value and particular distribution of the roadbuilding stones of the United States. It is to be expected that with the progress of the Survey such information will be rapidly gathered and put in shape for public use. Therefore the matter hereinafter presented may be regarded as a preliminary statement, rather pointing the way to inquiry than having of itself a considerable or permanent value.

INTRODUCTION.

All advance in civilization is closely connected with an extension of commercial and social communication. The most extended intercourse—that between the several great lands or continents—is necessarily by the way of the oceans or seas; that between the different divisions of the same area, though here and there it is accomplished by the navigation of lakes, canals, and rivers, is principally effected by land roads. Formerly these ways were altogether adapted to the use of horse vehicles. Of late the work of land ways has come to be divided between railroads and ordinary highways.

The effect of the use of land ways on the development of civilization is evidently great. It is easy to see that so long as men trusted to water communication for their commerce they were to a great extent limited in their dwelling places to regions immediately adjacent to the shore of the sea or to the banks of navigable streams or lakes. Even these methods of intercourse were precarious, as they were much affected by storms and in a large part of the earth by the winter ice. The result is that those peoples which have depended for their commerce upon navigation only have rarely become numerous or attained a considerable economic development.

The effort to establish commerce by land ways appears to have been one of the principal inducements which led to the domestication of the larger beasts of burden. Even before our kine served for milch cattle or for drawing the plow, they were extensively used as pack animals, for which purpose they were fairly well fitted. It seems pretty clear that horses were valued for that purpose long before the saddle became generally used for the conveyance of man. The failure to devise the stirrup until relatively modern times appears to indicate a lack of experience in equestration among the early peoples.

Although the distant land commerce of our own and other civilized countries is now principally effected by railways, and much of the local commerce is accomplished by the same means, the immediate well-being of every community is greatly influenced by the character and condition of its common roads. During the last half century the constructive energy of our people, so far as ways of communication are concerned, has been mainly directed to the extended iron ways; but we have now attained a stage in our industrial development where the attention of our people is again directed to the lesser but equally important routes. In part, at least, this recent interest in ordinary highways is due to a growing sense of the importance of the conditions which favor or hinder the local advantages of our communities. Men are learning that the most available good which the world has to give them is that which lies nearest their doors. A few years ago our agricultural communities were in a state of unrest for the reason that the cheap and fertile land of our frontiers invited the farmer to seek fresh fields and pastures new.

The frontier, so far as it is a land of promise, has now practically disappeared. The Eastern farmer of to-day knows full well that if he betakes himself to the West he must buy such good and easily cultivated land as is to be obtained from thrifty private hands and not from a generous Government seeking to divide a great heritage among its people.

All land transportation routes are, as regards their location, construction, and maintenance, profoundly affected by geological conditions, by the state of the earth over or through which they are made, by the character of the soil or the underlying rock, by the way in which the materials are affected by frost and rain and the pressure of wheels and of the feet of animals, and by the contours which the geological history of the region has impressed upon it. Only by knowing and considering these earth conditions is it possible to build and keep roads of good character at moderate expense. It therefore seems worth while to make some inquiry into the geological conditions of highways and to gather and set forth the knowledge which the earth science has to impart concerning them.

It will be well to approach the subject of highway geology with certain general statements concerning the conditions of the earth's surface which have a bearing on the construction of roads. In the earlier states of civilization all land transportation was effected by burdens put upon the backs of living beings. In the simplest state of commerce the small amount of carriage was effected mainly by packs on the shoulders of men. This appears to have been the way in which the aboriginal traders of this country conveyed their small wares over the land. In the next stage of development, where men have subjugated horses or cattle, the pack animal takes the place of the porter, each beast being able to carry several times as much as a man. Except for certain principal routes this state of internal communication continued in Europe well into the seventeenth century. It was maintained in some parts of this country, in the region east of the Alleghanies, until after the civil war, and it is still in extensive use in the Cordilleras of North and South America.

The wheel, though an ancient instrument, in use in Egypt and neighboring countries more than four thousand years ago, served first for chariots of war and state, and only gradually became an important instrument of commerce in the hands of the Romans. Until that eminently economic people developed the use of the wagon, the sled and the detached roller placed beneath the burden were the only instruments for conveying heavy weights over the land. The road, as distinguished from the unimproved pathway, is thus a relatively modern invention. Like nearly all the other advances in civilization, it brought men into a closer dependence upon the conditions of the earth. As long as burdens went upon the backs of men or beasts the condition of the trail over which the pack-bearers made their way could vary greatly

without materially affecting the usefulness of the route; but the use of the wheel imposes a far greater uniformity in the character of the way which is to be traveled. A trail could be laid across country without stirring the original surface and without much attention to grades, and it demanded little repair save that which use gave it. The road, on the other hand, requires labor and skill to make it reasonably traversable, and to bring it into the best condition demands architectural ability of a highly developed kind. The conditions of a good wagonway are such that it may be described as a hard open-air floor extended across a country. Its surface should be as nearly as possible level, and be composed of materials which will give the quality of surface required for the foothold of horses or oxen and at the same time yield as little as may be to the tread of the wheel. Perfectly to attain these conditions within the limits of geologic materials is impossible, yet with skill and the exact application of the means which the country affords it is generally possible to approach very nearly to the ideals of the arts.

OUTLINE OF HISTORY OF AMERICAN ROADS.

Before the settlement by Europeans the indigenous peoples of this country appear to have made little use of the native animals for carrying burdens. So far as known, the only Indians who used pack animals at all were the tribes on the west coast of South America, who had domesticated the llama, a creature which is able to carry a hundredweight for a distance of about 12 miles a day. The extensive and well-constructed roads, the remains of which still exist in Yucatan and the neighboring parts of Central America, may indicate that the prehistoric people of that district had some beast of burden at their command. It is the opinion of archæologists, however, that they were built to serve the purpose of footmen.

Except in western South America and in the region south of the Rio Grande, there were at the time of the first European settlements no roads in this country which were fitted for the use of pack animals. For a time the only way of making journeys was afoot or in boats. Although, as many expeditions show, strong men, with no more provisions than they can carry on their backs, may be able to traverse wildernesses such as originally occupied this continent, nothing deserving the name of commerce can now be effected in that way. Thus it came about that the first extended trade in this country was accomplished by means of boats, which traversed the waterways afforded by the rivers and lakes, a "carry" or portage being made from the headwaters of one stream to those of another. Owing to the fact that the only navigable ways leading into the interior of the continent were at first in the hands of the French, that people had for a time a notable advantage over the British colonies in entering the country and in trading with the aborigines.

For a time the European settlers along the eastern coast, between the Bay of Fundy and Florida—the colonies which became the original States of the Union—trusted almost altogether to the sea and its inlets for their communication. With the increase of population these settlements were pushed back from the shore, so that extended roads became necessary. At first these ways were often developed as trails adapted to saddle and pack animals. The original routes followed the Indian trails or the paths which the larger wild animals made by their migrations, and were little improved by art. Gradually, as the traffic became greater, these lines of travel were made accessible to wheeled carriages. At first this work was done in a very rude manner; afterwards, in cases where the ways were of importance, those who improved them were given the right to take tolls from the people who passed over them.

The earliest stage of pioneering in a frontier country of rude surface and covered with dense woods can be accomplished only by the use of pack animals. In such conditions the outer fringe of population is far in advance of the carriage roads, and those outposts can be kept in communication with the settled country only by the primitive means of conveyance. In this stage of development the ways are laid out with little or no consideration. They commonly follow the sides of streams, for the reason that these routes afford the least difficulties. In the colonization of Kentucky the first paths to the east followed, as far as possible, the courses of the rivers, and often made use of their beds, which were, of course, free from timber. Those streams were selected whose floors were shallow and smooth enough to afford a footing for beasts of burden. Thus, the trail was led up the waters of the Shenandoah and Roanoke, thence over the Alleghanies to the headwaters of the New River; thence to the Tennessee, and by its tributaries to Cumberland Gap. Beyond that pass the original paths again followed the brooks to central Kentucky. Even when the roads were made passable for rude wagons, they lay to a great extent in the beds of streams, or along their shores, that were bared at low water. When better roads were built they followed as nearly as might be the original courses of the route, for the sufficient reason that the settlers had grouped themselves along these paths. Thus it came about that the positions of the main highways of the Appalachian district were fixed, not by design, but by a chapter of accidents, in which the contour of the country, as determined by its geological structure and the sites of the old Indian and animal trails, which depended on the natural features, were guiding conditions.

The adjustment of the pioneer routes to the geological structure of the country is also well shown by the careful manner in which they were devised so as to escape the deep canyons of the James and the Kanawha, which lie almost in the direct path from Virginia to Kentucky. The first generally traveled route was the one above noted,

through Cumberland Gap. A second, though on the whole a later-used route, was by the valley of the Potomac to the headwaters of the Ohio, and thence by boat down that stream. A few immigrants used a path across from the headwaters of the James to the valley of the Kanawha, below the point where its gorge opens into a wide valley. The canyons of this river and those of the streams in the district are due to the peculiar structure of certain of the Carboniferous rocks. Thus the geological conditions of the area greatly hindered the access of population to the first fields of settlement which were established in the Ohio Valley.

The pack saddle in the Appalachian district was originally borne by horses. As the use of mules extended, it became customary to make them serve in this work. Still further on in the history of the country, bulls and oxen were often turned to this use. It may, in general, be said that the pack train was the effective pioneer mode of transportation during the time when the frontier was passing beyond the Alleghanies. Entering the flat lands of the Mississippi Valley, where navigable streams abounded, and where the character of the surface made it relatively easy to construct wagon roads, wheeled vehicles speedily displaced the pack train. It was not until the miners began to enter the mountainous portion of the far West that the pack saddle again came into general use.

So long as land transportation is carried on by pack trains, the geological conditions of a country affect the history of the roads in only a secondary way. The trails are laid across the surface on the most practicable lines, and no effort whatever is made to provide pavement. In fact, for the use of beasts of burden, where the weight is carried on the back, it is better that the road be not paved. The inconvenience which may be encountered from the mire that is apt to occur where there is no pavement is less great than that which results from the wearing of the animals' feet on a very hard surface. Even where the beasts of burden are well shod the damage which may arise from continuous treading on an unyielding surface is great. Nevertheless, as may be seen by the study of the history of our American roads, the wheelway has, in general, its course determined by what was originally only a trackway. Here and there, both in this country and in Europe, we may trace the narrow though often deep furrows of the old pack-train paths cutting over the hills on slopes too steep to be faced by wheeled vehicles. Thus, laid out rather by accident than design, these early trackways or wheelways often became the paths of considerable streams in times of heavy rains. South of the drift-covered belt in this country, especially in the regions where the soil is rather clayey, the roads, by water action, have often become deep natural ravines; sometimes, indeed, in the Southern States, they have attained a depth of 30 feet or more in less than a century of use.

In the Old World the lines of the ancient trackways are much more

conspicuous than in this country, for the reason that in the original seats of civilization pack trains served the people for a thousand years or more before the use of wheels was adopted. Except in the Spanish States of America, the use of the pack saddle was generally discontinued within a century after the settlement of the continent began. In fact, we may use the speed of its disappearance as an index of the enterprise and consequent commercial prosperity of a newly settled country. Thus, in New England the pack saddle appears not to have been used after the first century of its occupation, while in Mexico four centuries of development have not served to advance the people to a point where they have put aside this ancient instrument of conveyance. In general, it may be said that the English people have been very intolerant of the pack-train transportation, while the Latin folk, particularly of Spanish origin, have shown a disposition to cling to this primitive method of maintaining commerce. It is a noteworthy fact, however, that while the English-speaking people demand wheeled vehicles, and are prone to build roads over which they can journey, they have not, on the whole, been as good builders as the folk of southern Europe, who directly inherited the Roman tradition of highway construction.

At an early stage in the construction of American roads it became a general custom to support the wheels in wet parts of the way by means of cross-laid poles placed close together. In many cases miles of important roads were thus improved. This system received the name of "corduroy," though when thus prepared the term "laid roads" was applied to them. Those who have journeyed over these ways need not be told that they are extremely uncomfortable. These irregularities of the surface cause a sharp up-and-down movement of the wheels, and the sticks, soon becoming stripped of their bark, are very slippery to the horses' feet. Hence efforts were soon made on the better class of roads to provide against these evils by squaring the timbers and spiking them to bed plates. Out of this improvement probably came the characteristic American plank road, which, from the middle of this century till about 1870, was commonly in use in regions where timber abounded.

Although the plank road, when first made, is an admirable way, fulfilling all the required conditions, it soon wears out. The grain of the wood being parallel to the wearing surface, the timber soon breaks into shreds. Therefore another adaptation of the wood pavement was made, that known as the "wooden-block" pavement. For a time this system was very popular both in this country and in northern Europe. In the Old World it is still well esteemed, but in this country it has gone out of use. The reason for the difference is probably to be found in part in the unwillingness of our people to take a high degree of care in the repair of their ways, and in part it is probably due to the fact that American vehicles are driven at a higher speed than those of the Old

World, and thus pound the way in a more violent manner. Something of the effect may be due to differences in climate.

Yet another essay in the use of timber for road construction was made, according to the observations of the writer, in the northwestern part of this country during the last decade. Wood of any kind was shredded into a mass of narrow, rather thick shavings, commonly known as "excelsior" from the fact that it is used for making cheap mattresses which were sold under that name. This material was applied to the streets as a coating, about a foot in thickness. Although these excelsior roads were dry, elastic, and tolerably smooth, in every respect a great improvement on the mud which they replaced, they were rather costly, unenduring, and absorbent of filth. The system is interesting only as an index of the inventive motive of our people and as probably the last term in the series of wooden pavements.

METHODS OF USING STONE IN ROADBUILDING.

Wheeled vehicles were used for ages before it seemed to have occurred to men to do any particular work toward insuring a better foundation for them than the soil afforded. It may in general be said that although wheeled carriages are of very ancient date, their general use in commerce is less than two centuries old. The Romans made a considerable use of wagons on their great paved ways, but notwithstanding all the writing about Roman roads, the extent of these constructions was very limited, and almost all the inland commerce which then existed was carried on by means of pack trains. Thus, in England during the period of the Roman occupation, which endured for four centuries, the total length of good roads built was but a small fraction of that which now exists. It is probable that the ways made passable for wheels by the Romans in all the lands they occupied amounted to an aggregate of 10,000 miles in length, or about one-third the extent of the existing highways in the State of Massachusetts.

So long as wheels were left to deal with the natural surface of the earth the advantage which carriages afforded over pack trains was relatively small. The effect of the rotating disks is to cut through and to shear aside the soil materials in a way which leads to a partial locking of the wheels by the detritus. The very quality which makes the soil coating a suitable material in which the plants may search for food prevents its serving as a hard floor, such as is required for the best service of wheels. It may, indeed, be said that the better the soil the worse the way which it will afford to loaded vehicles. When first assailed by wheels the natural earth offers, through its coating of roots, which ordinarily lies just below the surface, some measure of defense against the disturbance. As soon, however, as this coating is removed or worn through, except at times when the earth is very dry, the wheels inevitably cut down below the true soil layer to a point where their further descent is arrested by a hardpan or other stony material.

The great Roman invention in roadmaking consisted of paving the way with flat blocks of stones strong enough to uphold the wheel. This form of pavement by means of stone blocks appears to have begun with the floors of the temples and other buildings, these floors being gradually extended so as to include a plaza and the streets of the city. Thence the extension into the open country in ruder workmanship was naturally brought about. Unfortunately the Roman system, though making a good road, is applicable in but few parts of the world. Only the few harder varieties of stone, such as the traps and the granites, are suitable for such use, and these are found only here and there, and usually in countries of rather limited agricultural value. Moreover, this method of constructing roads, even where the materials lie near at hand, is very costly; hence it came about that, until the middle of the last century, the highways of most places outside of the great cities were almost impassable to burdened vehicles except during the dry and the frosty seasons of the year. Even this moderate service was obtained at the cost of incessant labor on the roads which were much traveled, and of great waste from the need of repair of vehicles and from the excessive number of animals required to draw them. On such roads it was the custom to have the highway right very wide, so that the drivers could turn this way or that to escape the deep ruts worn by those who had gone before.

With Macadam's invention a new path was opened in the construction of roads. He discovered the fact that almost any stone of sufficient hardness to resist the tread of the wheels would, when broken into small bits and placed on the road as a coating of sufficient depth, in a short time harden under the travel. To Macadam we owe this interesting discovery concerning the process of cementation and matting, which causes bits of stone to become bound together when acted on by a roller or by wheels, until they form a firm, set mass. The peculiar advantage arising from the use of this principle consists in the fact that roads can in this way be constructed at a relatively small expense as compared with pavements made of blocks, and that the work can be done in many regions where suitable blocks for paving can not be obtained.

As yet the natural history of the macadam process is not well understood. It seems, however, to be due to the fact that almost all hard stones, when freshly powdered, exhibit more or less of the action which we recognize in what is known as water cement; that is, the powdered material sets into a firm mass.

If a mass of broken stones is allowed to lie with the fragments resting on one another, no evident trace of cementation takes place; but if the materials be repeatedly traversed by heavy wheels, or, better, by a roller of great weight, then as soon as the mass of broken stone is wet the cementation sets in. This fixing of the bits of stone together has been attributed in part to the interlacing of their rough faces when

they are driven together. Experiments seem clearly to show, however, that the effect is mainly due to the fact that the friction of bit on bit produces by the grinding action a sufficient amount of powdered rock to form the required cement. The binding strength of the cement varies much with different species of stone, but it exists in some measure with them all.

In some forms of detritus the cementing quality of broken stone is found to exist also where the powdered state has been brought about by natural action. Thus, in many places within the region affected by the ice of the last glacial period, we find gravels composed of rocks which, though broken up, have, on account of the overlying deposits, been protected from decay, their immunity from this action being shown by their prevailing blue color. It is a well known fact that such materials will cement together when placed upon a road and sufficiently rolled. On the other hand, the ordinary decayed, and therefore brown or reddish, gravels can not by any process be made to bind together. The fact seems to be that no decayed stone retains the capacity of cementation when powdered, though in some few cases, where the material is charged with iron oxides, it may, by the cementing action of the oxides, undergo a certain binding.

Experiments have shown that no ordinary flinty gravels free from iron oxides can be made to form a firm roadbed. No amount of rolling will produce the quantity of powdered rock necessary to unite the fragments together. Moreover, such powder as may be made has a relatively slight cementing power. On the other hand, if a considerable part of the pebbles be of limestone, rolling—either that intentionally done by machines devised for the purpose or that done by the wheels of vehicles—may produce enough cementing material to bind the mass, provided the pebbles are not too much decayed. In certain of these gravels, particularly in those transported by rivers, which often constitute a considerable part of alluvial plains, the action of decayed vegetation has led to the deposition of much iron oxide along with the pebbles. In many cases such deposits are firmly cemented in the places where they are found. When broken up and placed upon a road, the action of the rain water will bring about a recementation, so that these materials often make excellent road metal. Even where such gravels are not bound together in the bed, the pebbles will often unite when placed upon a road and well rolled.

Still further, we may note the fact that pebbles, particularly where they are of large size, even though they can not be made to cement in their natural state, will do so when broken into bits, for this process exposes undecayed surfaces from which the powder may be worn by the rolling action of wheels. It thus appears that there are three methods of applying Macadam's invention: by breaking stone taken from the quarry, by using stone broken by natural processes and not decayed, and by rebreaking pebbles which in their natural state can not be made to unite by the cementing process.

RELATIVE VALUE OF ROAD STONES.

Recognizing the fact that for general use a firm roadbed at moderate cost can be made only by the method of Macadam, the question next arises as to the relative value of the different kinds of rock which may be applied to this use. It may be noted that road stone needs to have two qualities: the material must be sufficiently hard to resist the action of the wheel, and the powder of the rock must have enough cementing quality to bind the fragments together into a firm waterproof mass. If the rock be too soft, the wheels will grind it into a powder, which blows or washes away, so that the covering of the road is soon lost; if the cementing action be too slight, the stones will be kicked or pulled out by the horses' feet or pushed aside by the wheels, so that the roadway comes to be strewn with rubble.

Experience shows that the binding power of powdered rock is usually so great that, except in certain of the flinty stones, we may trust the cementing action of the dust produced in rolling to hold the bits together. It is otherwise, however, as to the hardness which is required to resist the crushing action of the wheels. Here the variation is through a wide range. Most rocks are so affected by the tread of wheels that they are quite unfit for road stone, or at most are to be taken only where better material can not possibly be obtained. To understand the nature of the hardness of a rock it is necessary to note that it depends on two features: first, the resistance to disruption offered by the crystals or fragments of which the rock is composed; and second, the strength of the materials which bind these units together. It will thus readily be seen that the conditions determining the endurance of each bit of a macadam road are very much like those which affect the whole coating. As this matter is of much importance, it naturally leads us to some consideration of the structure of rocks.

In the first stage of the formation of ordinary rock, that in which materials composing it are laid down on the floor of a water basin, the mass is made up of fragments which in time become more or less cemented together. In some cases the bits are hard, as when they are composed of quartz feldspar, magnetic iron oxide, etc. In other cases, as where the fragments are of shells, coral, or other limestone materials, the bits are relatively soft. In none of these groups of rocks made up of fragments are the cementing materials likely to be strong, so that if the material does not give way on account of its general softness, it is usually ill adapted for road purposes, because the mass readily breaks up. Hence it comes about that the rocks which remain in the state in which they were first brought together and consolidated on the ocean floors are rarely good for roadmaking.

When such rocks as are above described become deeply buried beneath later accumulations, and are thus subjected to heat, and particularly where they are much compressed, as in mountain building, their

materials are taken to pieces and recomposed in the crystalline form. In this state the rocks become harder, or at least more dense, than they were before; limestones are changed to marble, the loose-grained sandstones to quartzite, while the clays are often altered into crystalline rocks, such as gneisses; and a yet more complete change may, it is believed, metamorphose some of the sedimentary rocks into granites, in which the chemical composition of the mass is the same as it was in the original fragmentary rock, but the substances are arranged in crystalline order.

Such changes as those last noted may occur without the materials composing the rock being reduced to the molten state; but it often happens that the rocks composing the earth's crust are, by volcanic heat, brought into the fluid state and forced up into crevices of the overlying deposits, where, on cooling, they form dikestones. In other cases they are poured forth from volcanic vents in the form of lava, which in time cools down, forming rocks of varied hardness. As these melted rocks harden—a process which generally goes on slowly—their materials commonly assume a crystalline form, and take on a texture which is usually much denser than that of rocks which have never been molten.

All rocks, particularly those which were formed near the surface of the earth or have been brought near the surface by the continuous down-wearing of the land, are subject to change by the action of percolating waters, such as are continually moving through the crust of the earth. We readily note these alterations in the features which mark the decay of stones, but they are equally apparent to the petrographer in more deeply buried and apparently unchanged materials. These alterations considerably affect the strength of rocks, sometimes converting those which were originally fitted for roadbuilding to a weak and, for that purpose, useless state.

In general, it may be said that the volcanic rocks, the dikestones and large crystalline masses, and the superficial lavas, are the best fitted for roadmaking; and of these the material known as basalt is much the best, though there are other groups of these once-molten rocks which are very well suited for such work. Usually the lavas which have cooled in fissures are stronger than those found on the surface of the earth, and this for the reason that when confined between walls of rock the lava has generally been subjected to great pressure, which has caused it in cooling to become a firm, set mass. In the lavas poured out on the surface of the earth the presence of large and small crystals, glass-banded structure, etc., often diminishes the homogeneousness of the stone.

DISTRIBUTION OF ROCKS SUITABLE FOR ROADMAKING.

Although the distribution of such rocks as we are considering depends on many conditions and is a matter of much detail, it may in general be said that they have a grouping which is related to the character of the

surface of a country, and this for the reason that the topography of any land depends upon the geological accidents which have affected the earth beneath it. We may, therefore, in a general way, note the following features in the distribution of the rocks suitable for making high ways.

In the regions of broad plains, such as are found along the southern coast-line of this continent and in the Mississippi Valley, we almost invariably find the underlying rocks little changed from their original state of water-made sediments, and the strata of which they are composed lie in a nearly horizontal position, indicating that they have not been affected by mountain-building forces. In such areas dikestones or lavas rarely occur.

Quartz, when it is found, as is sometimes the case, in large veins in which it has been deposited from water at depths below the original surface, often affords a tolerable material for macadam purposes. Owing to the very angular forms which the material assumes when crushed, it mats well together. The bits, however, are not really cemented into a mass, for the dust, unlike that from most other rocks, does not form a binding cement. Moreover, under the pressure of wheels and the beating of horses' feet the material passes rapidly into the state of fine sand, which is blown or washed away. Roads of this material rarely attain a very smooth state, and they wear out rapidly. On this account the vein quartzes are likely to prove of a secondary value in roadmaking.

Quartzites are rocks which were originally sandstones, the fragments of which have to a greater or less extent been dissolved and recemented into a firm mass. The nature of quartzites varies greatly. They often afford useful roadstuff, that which may be reckoned as of a second order of value, and are of much importance where better material is not to be had. Both quartzite and quartz are of importance in roadmaking in the Piedmont district of the southern Appalachians, where most of the other rocks which appear at the surface are generally too decayed for such use.

Another variety of siliceous material which is often very serviceable is known as chert. It consists of quartzose material which has been segregated in beds of limestone rock. When the limestone decays and is washed away, the cherty matter is often left in a rubblelike mass. In many cases the material verges into quartzite and is indistinguishable from it. The cherty residuum arising from the decay of limestone is of value in roadmaking in the southern portion of the Appalachians and in other portions of this country beyond the glaciated field, and also in some of the States of the Northwest where the amount of erosion accomplished by the ice-sheet was relatively small, so that the rocks which had decayed before the glacial time were not altogether removed.

Limestone rocks, though they vary considerably in hardness, are in

general much too soft for economical use in roadmaking, provided any other more suitable material can be obtained. The variety of such stone which is known as dolomite commonly affords a better rock than calcite, or ordinary limestone. Thus the beds of the Knox dolomite in Virginia, Tennessee, and the neighboring States generally afford a more enduring material than do the Silurian limestones of central Kentucky. Where the lime is commingled with clay the effect is generally to improve its value as road material; where the mixture is of sand and the mass is an arenaceous limestone, it is generally poor road stone.

Although the limestones must be placed rather low in the scale of rocks fit for use in roadmaking, their wide distribution, particularly in the Mississippi Valley, where the variety of materials for such use is small, gives them a great economic importance. They have for a long time been extensively used in Tennessee, Kentucky, and Ohio, and are beginning to be brought into service in the more western States. It is likely that in the next century they will serve in the construction of more miles of road than all the other kinds of stone which this country affords. It is therefore worth while to note that where the surface of a limestone road can be covered with iron ore the firmness of the mass is much increased. It may indeed be said that a coating of such ores, which are readily accessible in many parts of this country, adds greatly to the endurance of the way. Wherever rocks of the Clinton age are accessible they are generally found to contain one or more beds of iron ore, which, even where it is unfit for making iron, may serve, along with limestone, in roadmaking.

In the natural processes by which rocks are broken into bits, as by glacial action, by streams, or by the beating of the sea on the shore, pebbles are often formed. These fragments are harder than the rock from which they are made, for the reason that all the softer material has been worn out in the rough usage to which it was subjected. So far as solidity is concerned, the pebbles of any district generally afford the best roadmaking material which it contains.

The general unserviceableness of gravels for roadmaking is due mainly to the fact that the surface of the bits is smooth, so that the mass will not mat together in the manner of broken stone. There is, moreover, no undecayed rock dust between the fragments to serve as a cement; and even if there were such a binding material, it could not effectively fasten to the polished surfaces. Therefore, in almost all cases where it is desired to make a good and enduring road of gravel, the binding of the material must be provided for in one of two ways: the pebbles must be broken by crushing machines into yet smaller fragments, or a "binder" must be provided by using some firm cement.

In certain cases, particularly where the pebbly matter of a gravel deposit is to a greater or less extent composed of limestone, a considerable amount of iron oxide has been gathered in the mass. This effect

is due to the tendency of water which contains iron to lay down that substance and to take lime in its place when the opportunity of so doing occurs. These ferruginous gravels are commonly found in a somewhat cemented state, and when the material is broken up and put upon roads it again cements, even more firmly than in its original state, often forming a roadway of very good quality—smooth, hard, and impervious to water.

Certain gravels of the nature above described which are remarkably well fitted for roadmaking occur in the low-lying lands of western Kentucky, and probably in the neighboring States. They are known in commerce as Paducah gravel, from the fact that they have been considerably exported from the district about the town of that name.

In general, the clays, though often used in repairing roads, are totally unfit for that use. Each year much vain labor is expended in this country in the hopeless task of repairing roads with this material. In certain rare cases, where old nonplastic clays of a firm nature are obtainable, the material, when exposed to the air, will set in a way which makes it tolerably firm, yet the road surface thus formed is readily worn by the wheels into dust, which is washed or blown away.

The only fit use of clay for roadmaking is where it is burned in the form of bricks, which are carefully laid on some form of firm bedding and with the interspaces so filled as to prevent the penetration of water. In this burned condition the particles of the clay are partially fused, so that the mass has in good measure the firm, knit quality of those rocks, such as traps, which have cooled from the molten condition.

The other product of the natural disintegration of rocks, sand, may be dismissed with the brief statement that it is totally unfit to afford a bearing surface for wheels. It is true that when completely wetted, as on a flat beach which has just been bared by the retreating tide, the sand grains may be held together in a tolerably firm way by capillarity, due to the presence of water between small fragments, but this effect is lost with a small amount of drying, after which the mass resists the progress of the wheel in a very obstructive way.

In the mountain-built countries the rocks, owing to the pressure to which they have been subjected through the forces which led to the flexing of the strata, are generally very much harder than in the region of the plains. The limestones are likely to be changed to crystalline marble, though even in this state their softness makes them still essentially unfit for use on roads. The clay slates, and even the sandstones, may here be found sufficiently consolidated for use in road construction, though even when thus changed they do not afford materials of much value.

In mountain building, the conditions which lead to the formation of dikes and of other masses of rock which have consolidated from a fluid state, as well as of the hard veinstones, are commonly brought about. In most cases, however, these masses do not attain the surface of the

earth, or at least the surface which existed at the time the uplifting took place. It is only when the mountains have been subjected to much down-wearing that the originally deep-lying zone where the dikes and other igneous deposits were formed becomes laid open to the day. Thus, in the Alleghany and Cumberland section of the Appalachian Mountains, elevations which have been formed in relatively modern times, dikes are rarely to be traced, while in the Blue Ridge or eastern section of that system, whose ranges were formed in very ancient times, the down-wearing has disclosed very numerous masses of this nature. Thus again, on the island of Cape Ann, which has an area of less than 20 square miles, nearly four hundred lava-filled fissures have been traced, though owing to the drift and soil-covered character of the area these intrusions are disclosed only along the coast-line. Over a considerable part of New England such dikes could probably, on sufficient examination, be traced to the number of one hundred or more on each square mile of area.

The facts before noted make it plain why the regions occupied by ancient and worn-down mountains most abound in high-grade road-building materials. It is to these districts, indeed, that we must look for the best sources of supply of the rocks which are best adapted for road construction.

Owing to the peculiar geological work done during the last great ice epoch, when a vast glacial sheet lay upon and flowed over the northern and eastern surface of the continent, a large part of our land has been furnished with a peculiar class of materials suitable for roadmaking. The origin of this supply is as follows: As the glacial ice crept to the southward it rent great quantities of stone from the bed-rocks. These materials were borne southward, either contained in the slow-moving ice or hurried along by the violent currents of water which swept forward to the margin of the field. These torrents probably were impelled by the pressure of the overlying ice, which was often a mile or more thick, and which therefore forced the water onward with great energy. Thus impelled, the under-ice streams were able to bear toward the margin of the glacier great quantities of stone.

In the Appalachian district the effect of glacial action on the supply of road materials is only here and there of economic importance, for in most parts of that field the glacial waste lies on hard rocks which are suitable for roadmaking. But from the Hudson westerly to the Mississippi, the movement having been from the region of hard rocks north of the Great Lakes onto the soft rocks of the States which lie to the south of those basins, the effect has been to import into the last-named district bowlders and gravel of a quality which is better suited to roadmaking than any of the native varieties of stone. Even in its poorest form this glacially transported material is usually better than that which can be had from the underlying rock.

The original range of the glacial gravels has been here and there

greatly extended by the streams, which, flowing southward beyond the drift belt, have often carried quantities of the hard detritus for many miles beyond the limits of the ice-field. Thus the Ohio River, the line of which was touched by the glacier only at its headwaters and at Cincinnati, has conveyed quantites of drift gravel all the way to its junction with the Mississippi.

Where the glacial waste is composed of fine materials, as is the case throughout the greater part of the field which it occupies, the detritus rarely has any value for the roadmaker's use. Where, however, fragments abound not smaller than a man's fist, we are likely to find a store of rock which will, when broken in the manner of macadam, serve well in roadmaking. The utility of these materials is increased by the fact that each pebble or bowlder has been well tested for strength by the rude usage which it has met on its journey in or beneath the ice. Except where affected by recent decay, which commonly has not been great, these pebbles are generally sound enough to be of service in highway construction.

In the glaciated districts, and more particularly near the margins of the old ice-fields, there are apt to be numerous hillocks or more extensive masses of angular gravel, which have been well described by Prof. T. C. Chamberlin.[1] In a recent letter to the writer, Professor Chamberlin calls attention to these deposits as sources of roadmaking materials which may often prove of great value where suitable bedrocks are wanting, and even where the other forms of glacial detritus are unfit for such use.

Glacial deposits containing pebbles or bowlders which may afford good roadbuilding material abound in the northern part of Illinois and Indiana; they occupy the greater part of Ohio and western Pennsylvania, and occur in several States of the Northwest in sufficient quantities to serve an important use. As yet, however, they have not been made the subject of deliberate inquiry from the point of view of the roadmaker, and therefore can not be described in a detailed way.

A large part of the pebbly waste which may be made to serve for highway construction in the Western States is bedded with clays and sand, the mass at first sight promising little of value. Experience in the washing of other gravelly deposits proves, however, that by means of simple appliances the pebbles can at a small cost be parted from the useless material. The expense of this process may be accurately judged by work of the same kind which is done in obtaining those iron ores where the bits of ore are scattered in a mass of clay. In Alabama, where at the present time large quantities of ore are thus prepared, experience shows that with the pebbles constituting one-fourth of the mass the cost of the product need not exceed 50 cents per ton. Although this process can not profitably be applied in districts where good trap

[1] Hillocks of Angular Gravel and Disturbed Stratification; Am. Jour. Sci., Vol. XXVII, pp. 378–390, New Haven, Conn., 1884.

rock lies within, say, 100 miles by railway transportation, it will fit the conditions of a large part of this country.

The process above noted as accomplishable in an artificial way is brought about in a natural manner by the action of rivers. It may be assumed that in any country where pebbles intermixed with clay and sand occur in considerable quantities, masses of pebbles will be found in the stream beds or under the alluvial terraces which lie on either side of the existing channels. It must not be assumed that because deposits of such gravel are not visible a sufficient supply does not exist. The material can generally be obtained by dredging from the stream bed in the manner in which phosphate pebbles are removed from the Peace River in Florida, or by excavations made in the alluvial plains. Such sources of supply of road material are destined to be of great importance in almost all parts of the Mississippi Valley.

In those parts of this country which lie to the south of, or beyond, the glaciated districts, and where there has long been a considerable rainfall, the rocks exposed to the action of the weather have decayed by a process of leaching, which in many cases has removed hundreds of feet of strata from the surface of the country. As this process of decay goes forward the rocky matter is removed in proportion to its solubility. Thus, concretions of cherty matter which a bed of limestone may have contained often remain on or near the surface of the earth when all the rest of the deposit has vanished. In the Southern States we not infrequently find this residuum forming a layer many feet in thickness, the fragments being so much harder than the other available rock of the country that they are valuable as sources of road material.

In general these fragments of a flinty nature, derived from the rocks which have been dissolved away from the face of the country, lie in a relatively thin sheet, which is spread in a broadcast manner. Not infrequently, however, we find places where recent or ancient streams have washed over the material, taking from it the clay and sand with which it was originally mingled and leaving the mass of fragments in a condition well suited for use as macadam stone. In many cases the bits are much affected by decay, but when broken they may often be of fair service in roadmaking.

The residual deposits above described are generally found only on the surface of districts which are underlain by tolerably compact rock of considerable age. The reason for this is that only those rocks which have undergone a certain amount of metamorphism are likely to contain the siliceous parts which resist decay in the manner above alluded to. The principal exception to this general rule is found in the concretions of lime phosphates, which, as elsewhere noted in this report, plentifully occur in various relatively modern strata in the southern portion of the United States.

It should be observed that, except where concentrated by streams, the hard waste derived from rocks which have been leached away is generally hidden from view by the soil coating. The earthworms, ants, and

other animals which live under ground have the habit of bringing up the fine materials from the interstices of the fragments contained in this soil and depositing this small-grained detritus on the surface. The plants contribute to the same result, and the effect of this combined action is generally to make and keep an ordinary soil layer above the hard bits. The presence of the layer of cherty fragments can often be recognized in the gullies of plowed fields, and along the streams, where they are not bordered by alluvial plains.

In those parts of the country where tolerably good roadbuilding materials can be had from other sources, the residual cherty deposits arising from the decay of rocks are usually not worth the attention of roadmasters, but in many regions where there are no other sources of supply it may be worth while to search for these accumulations, and even to separate the hard fragments from the clay and sand by washing machinery, as is elsewhere recommended in the case of some of the glacial pebbles of the Mississippi Valley.

It occasionally happens that the process of erosion and deposition leads to the formation of deposits having a wide superficial extent, the materials of which are tolerably well suited for roadbuilding purposes. In most cases beds thus formed become covered by other strata and are therefore accessible only by mining, a process which is too costly for the needs of roadbuilding. In some places, however, as at Steep Brook, Mass., these accumulations of ancient detritus can be won by open cuts. At the last-named locality there is revealed by the uptilting of the Carboniferous strata a large quantity of decayed granitic rock, which was swept in Carboniferous times into a basin, forming beds which have locally a thickness of 20 feet or more. As this mass is composed of feldspar crystals and some quartz, it is fairly well suited for constructing roads, but as it is also useful as a fire clay it is not low enough priced for highway construction.

It occasionally happens that detritus of the older rocks having a quality suitable for roadmaking, being of relatively recent origin, has not been covered by later-formed strata, and thus lies as a broad sheet occupying an extended area of the earth's surface. This is the case with the Lafayette formation, which has been well described by Mr. W. J. McGee. The Lafayette beds occupy a large area—about 700,000 square miles—of the plains which surround the southern extremity of the Appalachian Mountain system. They are to a great extent composed of the débris from crystalline rocks which occupy that area. In general, these beds have a constitution which makes the roads constructed upon them of an excellent quality. Without the addition of other materials, they are often firm and smooth at all seasons, and in places they resist the destructive action of the frost. They afford the best natural roads in the Southern States, except those which lie upon the Ohio shale of Devonian age. With a little care the roads on this formation can generally be maintained in passable condition.

BLOCK PAVEMENTS.

In former ages it was the custom to pave highways with blocks ol stone. The more important of the Roman ways, the ruins of which are traceable in southern Europe, were thus paved.[1] In modern times the same method of construction is often followed, but it has become limited to routes which have an extraordinarily heavy amount of traffic. For ordinary roads its place has been taken by the macadam system. In the Telford modification of the macadam system provision is made for a lower level of construction, which, as would appear from the ruins, is somewhat like that which the Romans adopted for the traction level of their roads.

In the modern limitation of its use the Roman pavement may be regarded as appropriate for only the more important city streets, and for only such of these as for one reason or another can not be maintained with asphalt or brick coverings. The excessive noise and the wear on vehicles which block pavements inflict upon the public make their use undesirable.

As there are at present in this country many hundred miles of streets paved with blocks of stone, and as the use of these blocks seems likely to continue and to increase, a short account will be given of the sources of supply of these materials.

So far in this country paving blocks have been made in large quantity from granitic rocks only, in the main from granitites of the hornblendic varieties, and in part from the materials of that nature which have a uniform gneissic structure, though in New Jersey and elsewhere some success has been attained with basaltic traps. The conditions which have limited paving blocks, as regards the variety of stone, are substantially as follows: It is essential that the material should offer the utmost resistance to the crushing action of the wheel and of the horse's shoe, as well as the maximum resistance to the forces which tend to break it into fragments. In a word, it must be tough as well as hard. Still further, the stone must have three splitting planes, or rift lines, at right angles to one another, so that the blocks may be readily formed of regular cuboidal shape. So far as experiments have gone only the granitic and trappean rocks afford these conditions in a satisfactory manner.

As yet the paving blocks of this country have been produced mainly in New England and the neighboring States of the Northeast. Maine, New Hampshire, Massachusetts, Connecticut, and some other States

[1] It is commonly assumed that the Roman paved way was without other covering, and that the wheels and feet of the teams bore directly upon the stone block. From some personal study of these ways, as shown in their remains which have come down to us, I am inclined to believe that the stone was kept covered with a layer of earth deep enough to protect the unshod hoofs of the horses from the wearing which they would inevitably have encountered if they had trodden on the stone. Anyone who knows the condition of the bare foot of the horse, and who will examine the old Roman pavements, the blocks of which were sometimes of rough lava, is not likely to believe that these ways were used without a covering.

abound in deposits suitable for this use. Rocks of a similar nature occur in the Blue Ridge section of the Appalachians as far south as Georgia, though in the more southern portions of the region the process of decay has extended so deeply as in general much to reduce their value as sources of paving blocks. Still, such blocks of granitite of good quality are quarried near Atlanta, in southern Missouri, and in Wisconsin. In the Cordilleran district there are many granitic rocks which are likely in time to serve as sources of paving stone. It is probable that some of the granitic materials in the Ozark district of Arkansas may also serve this need.

It may be here noted that, so far, all the American experiments with paving blocks for carriageways have been made with small masses riven apart, and therefore with irregular surfaces. These roughnesses of fracture and the interspaces between the stones are what cause such pavements to be extremely noisy. Recent inventions have very much cheapened the cost of cutting stone by the method of sawing. The question therefore arises whether it may not be possible to pave with large rectangular blocks of granite, the edges to be fitted in the manner of closely jointed masonry, and the surface left smooth, or perhaps slightly roughened, to prevent the slipping of the horses' feet. Some difficulty may be encountered from the contarction and expansion in such a pavement with changes of temperature, but this might be met by the use of an elastic cement between the blocks. The endurance of a pavement of this kind would probably be much greater than that of one made of ordinary blocks, for the reason that the greater part of the wear which comes upon the faces of these riven stones arises from the up-and-down motion of the wheels over their rough surfaces.

PAVING BRICK.

Of late years the use of brick for paving wheelways has rapidly developed in this country. The system is ancient, having evidently been in use in Holland and elsewhere for a very long time. Although a tolerable pavement can be made of any clay suitable for the manufacture of ordinary building brick, provided the burning be effective, experience shows that to obtain the maximum hardness and toughness in such bricks it is necessary to make a careful selection of the materials, and an equally careful treatment of these materials as regards their admixture and the methods of burning. As yet none of the recently formed clays—those which have been made, and have remained since the making, on the surface of the earth—have been found as suitable for road-brick making as are those which are obtained from ancient deposits. There seems, indeed, to be some process, the nature of which is as yet unknown, that has taken place in ancient and deeply buried clays which has seemed to bring them into a condition where they bake into a peculiarly firm mass.

Clays which have been most successfully used for the manufacture

of paving brick in this country are obtained from the Coal Measures of the Ohio Valley. In appearance these clays are not very different from some of recent origin, but they are rather more compact, and probably by leaching processes have been deprived of the free lime, potash, and soda which would serve to make them melt into glass under the high temperature to which they have to be subjected in order to bind the grains of the material effectively together.

In general, it may be said, so far as other than practical tests can indicate, that nearly all the formations from the Tertiary to the Cambrian abound in clays of a nature well suited to the making of a good paving brick. In many cases it will be necessary to subject the material to a grinding process, for many of these ancient clays are of too firm a texture to be broken up in a pug mill. Still, it may be expected that it will often be advantageous to incur this expenditure.

So far as I am aware, no experiments have been made in manufacturing paving brick from the extensive clay deposits known as the Devonian black shale, which extends from western New York throughout a large portion of the valleys of the Great Lakes and the Ohio, and probably to the westward, beyond the Mississippi. Many portions of this shale contain a large amount of petroleum and related substances, such as paraffine. Before the discovery of oil wells in this country, the material was extensively quarried and treated in retorts in the manner of coal in the production of illuminating gas, the volatile products being won by the distillation. In this way about 15 per cent in weight of shale was removed, the remainder forming a friable siliceous clay, which appears to be well adapted for making brick of the quality needed for street pavements. In some cases the shale can be made to burn in open heaps, though it is probable that if used for brickmaking it would be desirable to have the firing done in kilns, so arranged as to recover the paraffine and other distillates. If it were not desired to make other use of the products of the retorts they would serve in their original gassy form for burning the bricks, a process which is now to a certain extent accomplished by the use of crude petroleum.

In this connection it is interesting to note the fact that many of the best deposits of brick clay which occur in the Ohio Valley and the neighboring districts on the east owe their good quality to the fact that they are made up to a great extent of materials from the Devonian shales.

It is very much to be desired that careful comparative studies should be made to ascertain the relative value of the clays in this country for the diverse uses to which they may be applied. At present it seems impossible to accomplish a work of this magnitude without the assistance of the Federal Government. The importance of such a study of our clays which are suitable for making paving brick is the greater for the reason that a large part of the Mississippi Valley, as well as much of the area of the Gulf and Atlantic States, is destitute of material

which, in its natural condition, can be used in roadmaking. Although it would be possible to import macadam rock from other fields, the cheapest resource will often be found in the excellent clays which abound in those parts of the country.

ACTION ON ROADS OF RAIN FROST, AND WIND.

It is impossible to understand the geological history of roads without some study of the effect which frost, rain, and wind have upon them. On account of the importance of their action, it will be necessary to consider these matters in a somewhat detailed way.

The effect of rain upon a highway is, first, to soften the bed, and next, to wash off the portion of the material which the temporary streams can bear along. On an ordinary dirt road the softening action is in high measure injurious, as it permits the feet of animals and the wheels of vehicles to penetrate below the surface. On a properly made stone road, such as devised by Macadam, as well as on all forms of block pavement, the road acts as a roof, shedding the water from its surface. If the way be skillfully planned the penetration of water from the sides is avoided, and thus the damage arising from the softening action, as well as from the influence of frost, is done away with. On all forms of dirt roads, and on the most of those made of gravel as well, the effect of the penetration of water in loosening the mass of the roadbed is serious, in most cases up to the margin of disaster. Here, indeed, we find the critical feature in all ill-constructed ways.

Where a hard road of macadam, or blocks, or other material impervious to water is properly shaped, the rainfall is quickly carried to the side ditches by the arched form of the way. On such roads the water never, even on steep grades, courses over the way for a much greater distance than its width. Thus arranged, the streams, even in a very heavy rainfall, do not gain much volume or attain great speed; therefore their scouring effect is but small. Nevertheless, the storm water, by removing the dust from the roads and by washing out the binding material between the stones, hastens the wearing of the way. This is especially the case where the macadam material is of the softer sort. Where the hardening is done with the firm basaltic trap rocks, the washing influence of the waters is not so serious. On dirt roads the rainfall, especially after times of frost, is the most serious agent of destruction.

When the frost enters the ground, the first effect is to convert into ice the water within the zone of its influence. In undergoing this change the fluid expands to the amount of about one-ninth of its bulk. The energy with which this expansion occurs is in all cases sufficient to thrust about the materials of the soil. So long as the road permits water to pass into it, and wherever ground water can penetrate from the sides beneath a way, however well compacted, even if it be quite waterproof, the action of frost is destructive.

There is a common opinion that frost works uniformly downward from the surface of the earth. A little observation on a freezing section of the soil will show this view to be erroneous. However uniform the texture and alike the materials of the detrital covering of the earth, the freezing process is extended irregularly downward. Although the whole of the earth for an inch or two in depth may become frozen at once, below that level the extension of the process goes on along particular lines, determined, it may be, by differences in the conductivity of the soil, but more commonly by the numerous and rather tortuous paths by which the surface water finds its way to the under earth. Thus it comes about that the expansive thrust arising from the formation of ice is carried laterally through the soil in such a manner as to shove the materials this way and that, but always advancing them in the direction opposite to that in which the freezing extends.

It seems likely that the growth of ice crystals, which is often so conspicuous a phenemenon on the surface of the earth on substances such as living or decaded wood, and which may be efficient in thrusting bits of stone to and fro, also goes on with the same effect in the earth. The writer has observed such crystals developing at a depth of an inch or two below the surface, and has seen reason to suspect their growth at a lower level.

The immediate effect of frost action on a well-paved road, where care has not been taken to keep the foundation dry, is to heave the pavement irregularly, the amount of the uplifting depending on the quantity of water which has become frozen. The effect of this irregular motion is to pull the cemented stones apart, and sometimes to form cracks through which the water can penetrate. Where the macadam is not well cemented, or where on a dirt or gravel road there are stones near the surface, the effect is often to push the larger bits upward to the surface. It may in general be said that all frost action is highly detrimental to a road, and that therefore the utmost care to exclude the water from the hardened part of the way, as well as from the under earth, needs to be taken.

It is likely that the process by which soils and other detrital materials on the steep slopes work downward is in good part accounted for by the thrusts which arise through the repeated freezings and thawings to which the soils of many countries are subjected. In a single winter it may happen that freezing to the depth of a foot or more, followed by thawing, repeatedly occurs, and each movement may result in pushing a fragment of stone for the distance of as much as an inch. As the motion will take place more readily down hill than up, the tendency is to move the detritus in the direction of the slope. Moreover, in all cases, frozen soil rises a little above the level it had before the frost penetrated it. When the frozen condition passes, the fragments return to a lower level, and in doing so are free to move down the slope. In this manner we may account for the fact that in countries much subject to frost mountain slopes of a given declivity are prevailingly less occupied

by soils than is the case in warmer climes. A result of this action is sometimes noticeable in the gradual movement of a roadbed down a slope on which it lies.

The action of wind on roads of all descriptions is considerable. The effect is to remove all the loose material of a fine-grained nature as soon as it becomes dry. On dirt roads and those of gravel the wearing action thus accomplished, though it takes place in a more even way, and therefore is less conspicuous, is often as great as that brought about by the rain. On the macadam roads the effect is considerable, but on the whole not seriously damaging, except where the pavement is made of rocks which easily powder. On the limestone roads of the Mississippi Valley, where the rock which is used powders rapidly, the dust is quickly swept from the roadway to the adjacent fields. At many points in Kentucky the writer has observed that a wide strip on the eastern side of the limestone roads has become noticeably enriched by the fertilizing dust borne to it by the prevailing westerly winds of the summer season.

EFFECT OF GEOLOGICAL STRUCTURE ON GRADES OF ROADS.

Almost as important as the character of the surface of a road is its grade—a feature which is determined by the contours of the country over which it is extended. Experience has shown that, except under peculiar conditions, it is very unprofitable to build roads having slopes exceeding what is commonly termed 5 per cent, i. e., 5 feet of fall in each 100 feet of length. A country which admits of roads being made over it with no greater slopes than 5 per cent may be said to be naturally well conditioned for roadbuilding. Where the grades necessarily exceed that angle of slope, the region may be termed disadvantageous for roadmaking.

It should not be supposed that a perfectly level country, or those regions which most nearly approach a horizontal surface, affords the best conditions for road construction. Such level fields are disadvantageous in two ways: In the first place, the unvaried resistance of the load to the traction of the animals is an evil, for it imposes on the creatures hard labor with no intervals of comparative repose, such as they have when the vehicle moves down slopes. Although there are no data to determine the matter, it seems likely that for the work of draft animals a way having successive slopes of about 6 inches in 100 feet, each slope occupying the length of about a mile, would be best suited to the needs. Something like the same inclination is demanded in order to secure an adequate drainage to the ditches on either side of the roadway. With a less slope than from 6 inches to a foot in 100 feet—the measure depending on the nature of the soil and of the rainfall—the roadbed can not be retained in a sufficiently dry state.

In a mountainous district, especially where the elevations have not endured long enough for the rivers to carve deep and broad valleys, the conditions under which the roads are laid out are generally such

as to impose a very serious burden, which we may call the grade tax on the transportation of the country. In certain sections of the United States, particularly in the Alleghanies, where there are many long, parallel ridges with few gaps breaking their rampart-like outline, the difficulty in the way of good roadmaking which the topography imposes is very great. The only methods of meeting this evil are as follows: Where the roads are properly planned, in relation to waterways or railways, it is generally possible to arrange the transportation so that it will not encounter the main divides. Generally, however, the roads are planned originally with reference to neighborhood convenience, and these local ways are afterwards made parts of through routes. The result is that when the country becomes thickly settled a system of highways exists which is a very serious tax on the earning power of the Commonwealth. The writer has estimated that in certain of the Appalachian States the unnecessary grade tax arising from the injudicious placement of highways amounts to as much as one-fourth of the total cost of wagon transportation over such roads. This evil can be met only by placing the main ways of each State under the control of authorities properly skilled in making roads.

Another evil arising from steep grades is found in the excessive action of the rain water which courses over them. As before remarked, the skillful road engineer provides for the speedy discharge of the water into the gutters by arching the pavement. It is, however, not practicable to give this slope from the center a greater fall than about an inch to the foot. The result is that the steeper the grade the longer the distance the water will flow over the pavement before it is discharged into the gutters. Moreover, these side channels, where steeply sloping toward the base of the declivity, have to be carefully paved, at an expense which may be as great as that incurred in building the traveled part of the road. It may also be noted that where the inclination of the way exceeds 1 foot in 20, there is, on certain soils of a prevailingly moist nature, a tendency of the pavement slowly to creep down toward the base of the hill.

In avoiding the difficulties incident to a rugged topography, the skill of the trained highway engineer is even more called for than in the construction of the roadbed. The latter task may be a matter of prescription, and can be done in a routine manner. The former demands a large element of judgment, which may be aided by a knowledge of the geological structure of the country. In order to avoid steep grades, the necessary recourse is to an elongation of the way by a system of zigzags. In laying out such a road it is necessary to take into account the character of the bed over which it passes, in order to avoid bad foundations or materials which are in motion in the manner of the slow landslides which often creep down slopes of high angle.

It is well to remark that in almost all steep slopes which are covered with loose material the débris, if it be not in the state of slow movement, has attained a state of repose which is so delicately adjusted to

its conditions of weight and declivity that a scarf for a roadbed cut on the inclined surface will again set the mass in motion, either in the form of landslides or a slower movement, which in the end entails a long-continued and serious expense in the way of repairs. Such movements are particularly common in loose materials in countries where the frost penetrates deeply and the ground becomes very soft in the time of thawing. In this country the mischances arising from ignorance on the part of those who have undertaken to diminish grades by the zigzag method have been very numerous, and in some sections, particularly in New England, the people have, by reason of such experience, become disposed to accept grades of 10 or 12 per cent rather than to enter on the perplexities which the elongation of the road might entail.

In many mountain districts, as the Swiss experience has shown, it is often better to carve an important road in the face of a precipice, even if it must be an almost continuous tunnel, than to incur the grade cost of directly crossing the elevation. In some cases, as in that of the tunnel which carries the main road from the city of Naples eastward, the construction is ancient. There are other European examples, dating from the Middle Ages or earlier, where important highways have been horizontally extended for a great distance through deep ridges. In the main, however, such costly highways are the work of this century. Although the first cost of such construction is large, the permanent economy often justifies the expense.

Even when a country is not mountainous, various features of its structure may produce a decidedly irregular surface where, though the relief may not be strong, the difficulties of adjusting roads in such a manner as to avoid a heavy grade tax is considerable. The commonest class of such surfaces is where, though the area may in general be that of a table-land, the streams have cut deep valleys, as is the case, for instance, in the limestone district of central Kentucky. In such a region the aim should be to place the main ways, where possible, next the streams, so that the outgoing produce of the fields may have the advantage of continuous down grade to rail or water ways. It often happens, however, that in such a region the rivers are in canyon-like gorges, where roadbuilding would be very costly. In general, in such indented tablelands the fit place for the main ways is along the divides, or watersheds, between the streams. Where such country is intersected by railroads it is usually best to organize its trunk wagon roads in the manner indicated.

The most perplexing surface over which a roadmaster is called on to construct main roads is that which has been shaped through the accumulation of glacial drift deposits on a preexisting river topography. In an area of this nature the elevations and depressions, which elsewhere are usually organized in a system which can readily be remembered, are disposed in a haphazard manner, so that nothing but a well-made contour map or a very careful and extended system of sur-

veys along different lines will enable the surveyor to lay out his way in a judicious manner. In the Commonwealth of Massachusetts, where the total length of public roads in an area of 8,500 square miles amounts, exclusive of city streets, to about 22,000 miles, it is difficult to find a stretch of road 10 miles in length which does not exhibit a number of blunders in construction due to an inadequate foreknowledge of the surface on the part of those who laid out the way. A close study of certain selected areas has led the writer to the conviction that in this State the average excess of grade over that which might have been had if the roads had been skillfully laid out amounts to about one-third of the total of all the declivities. The measure of the loss thus entailed may be better understood from the following estimate: The average grade of the Massachusetts roads is probably at least 2 per cent, which, for the length above given, makes the total height climbed by a vehicle which should traverse the whole of the length about 440 miles. Thus the saving in the aggregate ascension accomplished by the vehicles of the Commonwealth in the course of a year's work amounts to about 145 miles multiplied by the average number of trips made over the surface. As yet such computations lack statistical value, but they indicate an enormous expenditure of energy in the wear and tear of vehicles and of teams, in the time wasted by slow going, and in the successive journeys which the steep ways and small burdens entail. To plan roads discreetly in a drift-covered country, such as New England, demands good maps. To do the work well it is necessary that these delineations of the surface should be of a high order of accuracy. It is easy to show, however, that were the highways organized in the manner in which they could be by the use of such maps, the saving in the matter of roads would in time—indeed quickly—far more than repay the cost of the surveys. Herein we find what is perhaps the strongest of the many arguments for the prosecution of the topographic work of the U. S. Geological Survey.

In the greater part of this country the roads are already so far organized that any considerable change in their position will entail a great amount of expense. Experience shows, however, that where a region is well mapped and the highways are under the management of competent engineers, it is usually possible, from the system of ways, to select and maintain a set of main roads to which the others may serve as tributaries. It is also possible, by study of the traction charge as dependent upon slopes and the character of road surface, to establish a plan of improvement which will gradually reduce the cost of carriage by wagons.[1]

[1] In the present condition of road construction in this country it appears very desirable to have some simple method of testing the traction resistance of roads. It seems to the writer that the production of such contrivance is worth the attention of American inventors. It should not be a difficult matter to arrange a recording dynamometer in connection with an ordinary freight wagon which would give an index of the resistance on each section of the road under observation. A part of the evils of the road tax from which our people now suffer, especially their patience under the inflictions, arises from ignorance as to the precise amount of loss which the present ill condition of the roads entails.

Within the areas where the form of the surface is due to the action of glaciation, as well as in some of the Southern States, the occurrence of extensive peat bogs makes the construction of roads of desirable directness a matter of much difficulty. Except where the conditions are such as to permit costly fillings, experience shows that it is generally cheaper to bridge these obstructions than to build causeways over them. In all cases it may be safely reckoned that peaty matter will not support an embankment; although for the moment it may bear up the load, it will slowly slip away from beneath it until the weight finds its way to the bottom. The conditions, indeed, are substantially those in which a filling is made in water, except that the subsidence which takes place in peat may require years for its accomplishment. The only advantage in constructing upon peat rather than in water is that in the bog the side slopes of the embankment retain an angle of declivity generally lying between 45° and 55°, though it varies somewhat with the character of the peat.

In certain parts of this country, particularly along the shores from Massachusetts to the Rio Grande, the roadmaster has to contend with drifting sands, which, after the manner of snow, tend throughout the year to replace the constructed way with shifting materials which resist the movement of a vehicle in a very effective manner. The only known remedy for wind-blown sands is found in fixing the surfaces of the dunes by means of those species of plants which will grow under the difficult conditions which such fields impose. In Europe it has been found possible by the use of native and naturalized plants to cover the surfaces of wind-blown sands so effectually as to stop their progress.

In many regions where the sands were fixed by vegetation until the surface was broken by wheel, the earth material, when it becomes bared of its vegetation, is almost as mobile as the dune sands. Wherever possible, the trackway of such a road should be excavated and the place filled with suitable materials. Unfortunately, however, this method is inapplicable to many regions, so that temporizing expedients have to be sought. Some of these may advantageously be noted here.

Along a large part of our shore from Cape Ann southward to the Rio Grande the marine marshes behind the beaches contain very extensive beds of oyster shells. These materials are frequently accessible at low tide, and in almost all the lagoons they are readily obtained by simple dredging. Even where oysters no longer live, as in the region about Boston Harbor, the deposits nearly at the level of low water which are composed of these shells are very extensive, there being hundreds of acres of such accumulations lying a little below the muddy coating which covers the flats of Massachusetts Bay. Along the coast-line of the Middle States and in the contiguous country of the Southern States where higher-grade road materials are not accessible, these fossil oysters may advantageously be used. In the opinion of the writer, there are few stretches of 25 miles along this coast south of Portland, Me.,

where accumulations of this nature may not be found. It is worth while to note the fact that these deposits are rarely to be seen on the surface; they are commonly buried beneath a layer of mud or sand.

Most sandy roads may be much improved temporarily by covering them with a layer of clay. For this purpose plastic clay, that which when wet may be molded, as on the potter's wheel, is to be preferred. Mixed with the sand, it soon becomes hard; the clay serves as a binding material, and thus greatly diminishes the shearing motion of the road stuff under the pressure of the wheel. If nothing better can be obtained, the clay from marine mud flats should be used on the sandy seaboard ways, where the travel is sufficient to justify their improvement.

On ordinary sandy roads, where no other recourse is possible, it is advantageous to have two roadways adjacent to each other, one of which can be allowed to become covered with natural or planted grasses while the other is in use. The effect of the growth of vegetation is to promote a certain binding action. The influence of the fallow state is in many cases evident for a year or two after the way is again occupied by the wheels. In most cases, however, on exceedingly sandy roads it is best to favor the movement of vehicles in such a manner that the wheels will run in permanent ruts, with a strip of vegetation on either side. The passage of carriages can be arranged for by turn-outs. Where the traffic on the roads is considerable accommodation can be made by establishing two such trackways, each for vehicles going in one direction. In some parts of southeastern Massachusetts, especially on the island of Marthas Vineyard, these single-track ways have been long in use, particularly in the glacial sand plains. They are not found to be seriously inconvenient even where the number of vehicles amounts to as many as 50 a day. Turn-outs are arranged at intervals of about 100 yards, and are placed so that they may be intervisible.

In single-track roads the wheels, always moving in ruts, press the earth over which they move into a firm mass. The ruts become filled with dead leaves, which assist in binding the detritus. Experience shows that roads of this nature on level surfaces of sand can be kept in excellent order, as certain of them are in Dukes County, Mass., at an annual cost of less than $3 per mile, and this where the traffic is of a rather heavy kind. The only repairs which are required consist of filling in the ruts when they have become worn too deep for the wheels.

SOURCES OF SUPPLY OF ROAD STONE.

The most important question now before our roadmasters is that which concerns the sources whence the rock material to be used in highway construction may be drawn. On this account it seems well to give a statement of those facts which are at present known concerning the distribution of such rocks. It should be noted that although the geology of this country has been extensively studied, and is in general well ascertained, scarcely any attention has been paid to the value of

the different stones in roadmaking, or to their distribution. The writer has to rely, therefore, upon a limited experience which he has personally gathered during recent years, and on information which he has been able to obtain from other officers of the U. S. Geological Survey, and from the publications of the State surveys.

From the point of view of its road materials the United States may be conveniently divided into five areas, which, be it said, are only in a general way distinguished from one another. These are as follows: New England; the Appalachian belt, from the St. Lawrence southward, including all the southern elements of that mountain system; the Coastal Plain, extending from New Jersey to Texas; the Mississippi Valley, including the plains country westward to the Rocky Mountains; and the Cordilleras, including the western third of the country. These several districts will now be considered in succession, with the intention of pointing out the most available roadbuilding materials, so far as they are known in each.

NEW ENGLAND DISTRICT.

The district of New England is in general remarkably well supplied with the rocks which are fitted for roadbuilding. It is, indeed, doubtful whether any other portion of this country so abounds in stones suited to this use. On the western border of this area, in the Berkshire Hills and the Green Mountains, there is, it is true, a field where the stone is generally of a schistose character, and of a nature which is not usually suited to roadmaking. Moreover, in this district, though dikestones occur, they are relatively infrequent, and the fissures which they fill are usually rather narrow. Fortunately, however, in the valley of the Connecticut River, from near its mouth to the northern border of Massachusetts, there is a great array of trap rocks and of lavas which were poured out on the sea floors of the Triassic age—rocks which are not only of excellent quality for roadmaking, but which occur in deposits forming high cliffs and are therefore very well placed for quarrying. These Triassic traps and lavas are the most valuable roadmaking materials in the district which we are now considering. From them the region westward of the Connecticut, as far as the Hudson Valley, can be conveniently supplied.

East of the Connecticut, and thence to the coast-line, trap dikes are of frequent occurrence and granitic rock is abundantly found, but the deposits of trap are generally costly to work, for the reason that they lie in narrow crevices, and the granitic rocks afford road materials of only the second class. Fortunately, the greater part of this area lies within 100 miles of the great trap deposits of the Connecticut Valley, and can therefore be supplied from that source. As we approach the coast-line of New England the trap dikes become more numerous than in the interior districts, and though none of them are as large as those in the valley, we not infrequently find deposits of 100 feet or more in

width. Some of these are readily workable. One such in Waltham and another in Salem, Mass., are now the seats of a considerable broken-stone industry. In Rhode Island the dikes are few and mostly of small size, and none have yet been found which are likely to be worked for road materials, except it may be the deposit of magnetic iron ore in the town of Cumberland known as Iron Hill. The same is the case with the sea border of Massachusetts, except for a single dike in Salem, above referred to, and another in the town of Quincy known as Houghs Neck, where a dike having a width of about 100 feet may perhaps afford the conditions of profitable working.

On the coast of Maine there are very many large dikes, as well as some ancient lava-flows. These deposits are most numerous along the coast from the mouth of the Penobscot to Passamaquoddy Bay. None of them have been carefully examined to determine their value for use on roads, but it seems probable to the writer that owing to their generally good character and their convenient position in relation to harbors they are likely to be made the basis of a considerable export of road stone to points along the Atlantic coast.

In the interior district of Maine, owing to the great thickness of the drift deposits and the generally poor quality of the bowlders, road stuff of a suitable grade is hard to find. It may, however, be obtained at small cost from the rocks of the coast belt.

Eastward of Maine, along the shores of the Bay of Fundy, trap dikes having in general the character of those of the Connecticut Valley again occur. Although this district is outside the United States, and therefore beyond the field to be considered in this report, it may be said that the Bay of Fundy offers an interesting field for exploration on the part of those who may wish to obtain cheaply traps accessible for water transportation to the New England coast.

It may be remarked that only one field of New England has been found unsupplied with stone which could be made tolerably serviceable for roadmaking. The island of Nantucket, being made up of sands and clays of glacial age, has so few pebbles or bowlders in the mass that it will be necessary to import stone for its roads.

The drift materials of New England are, except in the Berkshire Hills, the Green Mountains, and the central and northern parts of Maine, generally well suited for road purposes. In fact, if it were not for the ample supply of excellent bed-rock stone they would have distinguished value. As it is, they may be reckoned as a valuable resource in the southeastern portion of the area, where, as in Barnstable and Dukes counties, Mass., good road stone is not otherwise accessible.

APPALACHIAN DISTRICT.

In the Appalachian section south and west of the Hudson the most satisfactory source of road materials is to be found in the traps of Triassic age, the equivalents of those in the Connecticut Valley, which

are found on the eastward side of the Blue Ridge or its northern equivalents, from near New York to South Carolina. At the northernmost point of their appearance in this district, in the Palisades of the Hudson, these traps are admirably placed for convenience of transportation. They are of excellent quality and of great thickness. They can be taken by ship to the open sea, by boat through the Erie canal, or by railway to any point.

Southward in New Jersey the Triassic traps are abundant, and so placed that they may be very conveniently worked. In this field, as in the Hudson, traps of this age generally exhibit the columnar structure so common in the basalts, a feature which makes the rocks easily broken from the quarry.

In the New Jersey highlands hornblendic trappean rocks occur in large quantities about the iron mines. The waste heaps afford quantities of these materials, conveniently placed for use. Although not of the best quality, this stone may be reckoned as fairly well suited for macadam roads.

The rocks known as gabbros, which occur in western Delaware and about Baltimore, appear to be promising sources of supply for such materials. They are evidently of a very firm nature.

From New Jersey southward the Triassic traps occur in small masses. They have not been explored, and it is doubtful whether they are so placed as to have much value for roadmaking. In this more southern section resort must be had to the trap rocks of the Blue Ridge or its southern equivalent, the central ranges of the Smoky Mountains. Here, again, little is known as to the distribution of these rocks, but it seems likely that exploration will develop them in suitable quantity and quality as far south as northern Alabama. In this region, as elsewhere, there is great need of extending our knowledge of road-building material.

In the Smoky Mountain district there is a number of localities where extensive veins of magnetic iron ores occur, though owing to the admixture of various impurities the material is not fit for making iron. It seems not unlikely that these ore deposits may serve in the construction of roads. Some observation which the writer has made leads him to suppose that fragments of this rock will cement well and prove strong against the tread of the wheels. There are also numerous crystalline rocks in this field, more or less resembling granite in structure, which will afford good road stuff, though it is less valuable than the materials above mentioned.

At various points in the Appalachian district, particularly in the Cumberland sections, quartzites abound—beds which, though originally sandstone, have, in the processes of mountain building to which the rocks have been subjected, been converted into a flinty material, which is tolerably good for use in roadmaking, though it does not cement very well and is not very resistant to wheels.

In the Alleghany and Cumberland districts the shales, particularly those commonly known as the Devonian, or Ohio, shales,[1] constitute an excellent material for roads where the traffic is not heavy. It is a peculiarity of this material that it breaks into thin, shingly layers, which are moderately tough, and although they do not bind well together, they serve by their form to uphold the wheels. Those who have traveled much in this part of the country must have observed how very good the roads are where they pass over beds of this shale. These ways can be maintained in excellent condition with very little work. They often remain smooth and hard though left quite without care for a score of years. Although the materials from the Devonian beds are not sufficiently valuable to make it worth while to transport them for considerable distances, they are worth attention for use in the neighborhoods where they occur.

We may also note the value of the numerous bedded iron ores which are found at many points in this district, particularly in the fields to the west of the old central mountain axis. These deposits, when too lean to be worked in the furnace, often afford very good road materials. They are particularly adapted for use as a cement with which to bind together the fragments of other kinds of stone. The iron oxide thus proves in many cases a valuable resource.

The low-grade iron ores which we are now considering are so widely scattered throughout the Mississippi Valley that it is difficult in a report of this nature to give any indications as to their locations which will be of value to the roadmaster. In general it may be said that wherever a limestone occurs beneath a considerable thickness of shales and sandstones the upper part of the limy layer will be found to be replaced by iron oxide. The upper limestone beds of the Clinton, the Oriskany, and the sub-Carboniferous are commonly thus transformed, while here and there in the Coal Measures thin layers of such ores exist. The existence of these beds is frequently revealed by pits dug in the earlier days of this century, when iron was high priced and the early settlers were ever seeking an opportunity to engage in its manufacture.

In and about the southern Appalachians there are many deposits of conglomerate, some of which are likely to prove of considerable value to the roadmaker. The oldest of these beds, that known in eastern Tennessee and western North Carolina as the Ocoee formation, would be of value as a source of road stone but for the fact that it lies in a district which is well provided with more serviceable materials. The conglomerates of the sub-Carboniferous age, occurring as they sometimes do in regions destitute of other hard rocks, may occasionally prove of value, particularly in Pennsylvania.

[1] As there are several Devonian shales, I have, in the reports of the Kentucky survey, second series, endeavored to affix the name Ohio shales to this deposit.

COASTAL DISTRICT.

For present purposes the coastal belt of eastern United States may be taken to include all the lowland districts lying between the Hudson and the Rio Grande which are underlain by deposits recently formed on the sea floor. So far as these deposits extend, the country is imperfectly provided with rocks suitable for use in roadbuilding. If we except the Lafayette formation (see p. 277), the newly made beds themselves are usually of an incoherent nature. There are, so far as known, no dikes within this district, and the recent strata hide all the lower-lying and more firmly organized beds. Therefore the better kinds of roadmaking materials used in this district will have to be imported from beyond its limits.

Fortunately for the needs of the coastal belt, roadbuilding stones of good quality are generally accessible in the country lying to the north of that area, and this without excessive cost of transportation. The greater part of the area is within 200 miles of the old axis of the Blue Ridge, where tolerably good road stones abound. The remainder, the region near the Mississippi, is poorly provided; it seems likely, indeed, that materials from which macadam can be made will have to be imported into that section by sea from the North Atlantic coast, or perhaps by water transportation from the Ozark Mountains and other regions in Arkansas and Missouri, where a number of rock species well suited for road work occur in positions near the navigable rivers.

Along the costal belt of the Atlantic and for a considerable distance westward in the Gulf States the wide distribution of the Lafayette formation affords the country fair opportunities for good roads at the minimum expenditure. Here and there this deposit contains an excessive amount of clay, and is, therefore, particularly in the winter season, likely not to uphold the wheels. In general, however, if the roadbed is kept dry by means of deep side ditches, the way can readily be maintained in what may be described as that of a first-rate second-class road. This remarkable deposit extends in its characteristic aspect from northern Maryland to central Florida. Mr. George H. Eldridge informs me that near Bartow Junction, in the latter State, the deposit takes on an even better character, forming a compact road, the material being indeed of such value that it is shipped to the chief towns, where it is used in making streets.

At Gainesville, Fla., beds probably of the same age, but containing more or less lime, both carbonate and phosphate, and also some iron, are used for roadmaking and shipped to various places in the central part of the State.

Along the banks of the greater rivers which have their headwaters in the Appalachian uplands there occasionally occur gravel deposits the pebbles of which, being of crystalline rock, are fit, after crushing, to be used in making roads. The quantity and quality of these gravels

are not well known. They seem likely, however, to have an importance, for the reason that they occur in a district singularly barren of hard rocks. Of these the Paducah gravel is the most characteristic deposit (see p. 273).

In the central part of western Florida deposits containing abundant pebbles of lime phosphate abound. Similar beds exhibiting the same materials in less quantity occur at points in southern Alabama and Mississippi. Where these pebble phosphates are of the first quality they are of such commercial value that they can not well be looked to as a source of road material. Experience shows, however, that the deposits of pebbles at certain points have peculiarities, such as an excess of lime carbonate, which make them of little value as a source of fertilizing material. In such cases the pebbles may well be used, after breaking, for road purposes. Pebbles of lime phosphate are harder than ordinary limestone, and the fragments cement well together, so that the material forms a good road metal, one which may be of great value in a region where roadmaking stones are of rare occurrence and the need of hardened ways is very great.

It seems not unlikely that some of the districts about the ports on the Gulf of Mexico may well look to the crystalline rocks of the West Indies as sources of road material. A large trade in coal and breadstuffs is now growing up between our Gulf ports and those about the Caribbean, and return freights, or at least ballast, of roadmaking stones might well be brought to this country.

In many parts of the coastal belt, especially in and near the great cities, it will doubtless be found advantageous to use brick pavement for the wheelways. On this account it is important to note the fact that the clays suited to making high-grade brick occur plentifully in various sections, while fuel, either coal or wood, is generally not remote. In some sections it will probably be found to be cheaper in the end to pave with bricks made from these local clays than with macadam stone brought from a great distance, for although the first cost of such pavement is high, the expense of its use for a term of twenty years is relatively not so.

In certain sections of the coastal belt, particularly in those regions next the shore, some use is made of marine shells, which frequently make up all the mass of extended beaches. Roads thus constructed are of excellent quality, but their endurance under traffic is so poor that except where the carriage of the shells is but for a short distance they can not be regarded as economical.

At some points on the coast of Florida and elsewhere the beach shells have become cemented into a compact limestone which is fairly serviceable for building purposes and is locally essayed as a roadmaking material. In view, however, of the ease with which the stone grinds into dust, it is not to be commended, save where no better material is available.

The State of Texas, owing to its great area and the prevailing bad character of its roads, requires a somewhat special treatment from the point of view of the materials within it which are fit for use on highways. An excellent sketch for such a study has been made by Prof. Robert T. Hill,[1] of the U. S. Geological Survey. The following statements concerning this district are condensed from Professor Hill's memoir:

At Pilot Knob, 7 miles southeast of Austin, there is a large mass of basalt which is admirably adapted for roadmaking. This substance can advantageously be used, at least for a top coating, on the roads lying within 50 miles of the locality. Other localities of basalt are known in the country south of Austin, but details concerning the quality and accessibility of the materials are lacking.

Next in value to the basalt as road material are the gravels which are considerably developed in different parts of the State. These vary a good deal in origin and character, but are all worthy of attention.

The plateau gravels, deposits which are not distinctly related to the streams, are thus described by Professor Hill:

> Along the eastern side of the Black Prairie region are immense deposits of gravel, the pebbles being of various sizes and composition. In the northern portion of the State the gravel is mostly composed of quartz and chert derived from the ancient mountain region of Arkansas and the Indian Territory. East of Austin and to the northward it is mostly composed of flints derived from the Grand Prairie region. These are often as large as a human head and would serve well for a Telford foundation, but as often now used they are an injury to the roads. In many places, however, this gravel is of sufficient size for top dressing and occurs in inexhaustible quantities.

Along the principal streams in and near the Black Prairie region, as in the case of the Brazos, the Red, and the Colorado rivers, there are extensive deposits of gravel well suited for roadmaking. In Travis County the terrace deposits of the Colorado contain gravel for a distance of from 1 to 3 miles on each side of the river. Where these deposits come to the surface the roads are excellent. Where they are wanting the ways are almost impassable.

Akin in origin to the pebbly gravels are the deposits of flints which abundantly occur on the flat-topped divides of the Grand Prairie to the west of Austin. They are residual materials left from the disintegration and removal of the chalk and chalky limestones.

Professor Hill notes the occurrence of several chalky limestones, of which that known as the Shoal Creek limestone seems to be the best suited for roadmaking purposes. Lower down in the series of the chalky limestones is that known as the Washita. Although Professor Hill considers these limestones as fit for roadmaking, the hand specimens which I have seen indicate that the material is rather too soft for such use.

[1] Roads and Material for their Construction; Bulletin of the University of Texas, December, 1889.

Beneath the Washita limestone there lies a deposit of much harder lime rock, having in general the character of the Cretaceous and Jurassic limestones of France and Switzerland, materials which have been found to be fairly well adapted for roadmaking.

The yellow marls, Fuller's earth, and oolites which occur in the Grand Prairie district appear from the descriptions of Professor Hill to afford satisfactory materials for local use.

MISSISSIPPI VALLEY AND GREAT LAKES DISTRICT.

The most difficult problems connected with road construction in this country are presented by the central or plains section of the Mississippi Valley. Throughout this great expanse of nearly a million square miles the underlying bed-rocks are horizontal and generally too soft for road purposes; they are, moreover, essentially without dikes or volcanic deposits.

In considering the importance of the roadway problem in the Mississippi Valley, the fact should be noticed that the region is well adapted to tillage, with the exception of a small portion of the territory west of the Mississippi where the rainfall is insufficient. As a whole, it is the most fertile area of equal size in the world. The most serious qualification to its agricultural value is that which arises from the badness of its highways and the difficulties that have to be encountered in finding suitable materials with which to build them.

It may be assumed that the underlying rocks of this field are essentially unfit for making roads, though they may, perhaps, in default of better, be used for that purpose. The least objectionable of the native stones are the hard limestones of Silurian and Devonian age. These rocks are easily quarried and broken; they compact well under the roller, or even by the tread of wheels, but the rate of wear per unit of traffic is so great that they can be maintained only at a large annual cost. The amount of damage done to the road to a given amount of travel is probably five times as great as upon a road formed of the better trap stones.

Poor as the limestones of the Mississippi Valley are for roadmaking, nearly all the macadam roads which have been built in that section are made of such rock. One effect of its use has been the establishment and long continuance of the toll-road system, a system which confesses that the roads are too costly to be cared for at the expense of the community which they serve and are therefore turned over to stock companies. It seems to the writer that the perpetuation of the toll-road system in prosperous communities, such as those found in the limestone districts of Kentucky, can be accounted for in part, at least, by the great cost of maintenance of such ways which the use of limestone in their construction entails.

Next after the limestones, in generality of distribution, we may reckon among the possible roadbuilding materials the drift deposits of the

Mississippi Valley district. These are plentiful, and afford the most valuable pebbles for roadmaking in the States of Ohio and Indiana, but they deserve consideration in northern Illinois, Michigan, and the States farther to the north and west. No studies having been made of these deposits from the point of view of their use for road material, only the most general information concerning their occurrence can be given here. It may be said, however, that the value of these beds rarely appears on superficial inspection. It often happens that although the surface may appear unprofitable from its sandy or clayey nature, pebbly or bowldery beds exist at a slight depth. To elucidate these features of the distribution of these materials will require a careful inquiry. When found, these deposits of rock fragments will have to be separated from the finer detritus, either by screening or by washing, and the bits thus obtained will have to be passed through crushing machines in order to obtain the fresh fractures which are required for macadam roads. In general, it may be said that about one-third of the Mississippi Valley district is likely to obtain tolerably good road-building from these deposits of pebbles imported into it by glacial action.

The pebbly waste from the glacial deposits has in many cases been so concentrated by stream action that the fragments have been accumulated in the river beds and alluvial plains apart from the finer material. As these deposits come to be sought for they will doubtless be found valuable sources of supply (see p. 274).

Turning now to the sources of road materials which exist on the periphery of the Mississippi Valley district, we note the following facts: On the north of this field, in Canada and northeastern Minnesota, as well as in the upper peninsula of Michigan, there exists a great array of dike-stones and other hard crystalline rocks which are well suited for road-making. Although these materials are rather remote from the region south of the Great Lakes, it seems likely that they may be of some value as sources of supply.

On the east of the great valley the highway road materials of the Atlantic Coast belt may be reckoned as too far away to be of use. In the Smoky Mountain district of western North Carolina there are, as before noted, rocks suitable for roadmaking which, without undue cost, can be made to serve the needs of a considerable section of the southern part of the Ohio Valley. The Ozark Mountain area and the neighboring parts of Missouri, though their geology is as yet imperfectly known, seem likely to afford good road materials from their novaculites, or whetstone rock, as well as from their dikes and other crystalline materials. This source of supply should be available for the States of Missouri and Arkansas and parts of neighboring States. On the western border of the area the traps and lavas of the Rocky Mountains may be reckoned on for the supply of road stuff for a considerable area near the eastern margin of the Cordilleras.

It appears evident to the writer that in a large part of the Missis-

sippi Valley it will in the end be found most convenient and most economical to construct the foundations of a macadam road of the cheaper and easily obtained limestones or other sedimentary rocks, covering the surface to the depth of not more than 3 inches with imported traps of the best quality. In this way the strength of the road is obtained by the use of cheap material, while of the dear only enough is used to insure a hard bearing for the wheels of the carriages and the feet of the draft animals. In those parts of the valley where the distance from trappean rock or glacial pebbles is so great as to make macadam roads undesirable, recourse will necessarily be had to brick-paved ways. In general, these will be so constructed as to afford the narrowest possible trackway for winter use, with a broader ordinary dirt road for summer travel.

The probability that brick pavement will be extended from the cities to the country roads makes it desirable to have a careful study instituted as to the relative value of the clays of this region which are fit for making bricks of the quality required for such pavements. As yet the value of these clays has been proved but in few localities. There is reason, however, to believe that they are of widespread occurrence, and the coals which are to be used in burning the clay are also present or near at hand in the greater part of the area.

So little has been done toward investigating the materials suited for roadbuilding in the central portions of the Mississippi Valley and Great Lakes district that not much can be stated in this report which will be of value to those engaged in constructing highways. In the following pages, however, some indications will be given which may prove useful.

East of the hundredth meridian and north of the Ozark field the valley of the Mississippi contains, so far as known, very little in the way of trappean or other igneous rocks. There are reasons, however, to believe that a detailed inquiry may here and there reveal deposits which, though not conspicuous on the surface, may, when properly opened, prove to be of value. Thus in Kentucky, quite by chance, two dikes of a traplike nature, known as peridotite, have been discovered in recent years. These masses, unlike most of similar nature, are not marked in the topography, and were noticed only by reason of their decayed portions, which made a peculiar stain upon the surface that led inquiring land owners to dig into them. So far the inquiry into their constitution has been limited. The openings have not penetrated below the zone of superficial decay, so that it is not known to what extent they may afford road materials, though it may be said that the indications are promising for such a supply. It is eminently probable that there are many such deposits, though in all cases it is to be feared that the material will have value only on account of the decay to which it has been subjected at a considerable depth beneath the surface.

The most widespread of the firm rocks in the Mississippi Valley are

the limestones, those which range in age from Cambrian to Carboniferous. As may be seen by consulting any geological map of this part of the country, the limestones of this valley have a wide range. At almost all points east of the Mississippi River and north of the Gulf States, and in the tier of States immediately to the west thereof, there are few points where accessible deposits of these limestones are more than 50 miles away. It is true that the roads made from them will, as before noted, lack endurance, and are therefore sure to be very costly, on account of the expenses of repair. They are destined to be much used, however, at least in the first stage of road improvement of that district.

The lower-lying limestones of the Mississippi district, those of Cambrian and Silurian age, have been extensively essayed in road construction in the central and southern portions of the Ohio Valley. As a whole, these stones, though in appearance tolerably firm, have been found too friable to afford good road materials. The Upper Silurian limestones, particularly in the region within 100 miles of Cincinnati, are generally of a firmer texture than those of lower horizons, though the material is occasionally rather sandy. By proper selection of the beds from which the supply is obtained it seems likely that good road material may be secured from these deposits.

The Carboniferous limestones, which are extensively developed in the northern half of the Mississippi Valley, are in general too soft for profitable use on roads, although, as almost anything is better than miry ways, it may in some places be advantageous to use them.

Here and there in the great section of rocks displayed in this part of the country considerable sections of quartzite occur. Thus in eastern Tennessee and in neighboring parts of Kentucky and Virginia a portion of the sub-Carboniferous strata, elsewhere of a limy or clayey nature, has a quartzitic character, affording materials tolerably useful for roadmaking. The fragments from it mat together in a rather firm manner, and while they grind up beneath the wheels, they serve as well for pavement as any deposits of their general nature. In northwestern Iowa and southwestern Minnesota, as Mr. W. J. McGee informs me, an ancient quartzite, probably of Algonkian age, is coming into extensive use as a source of road material in and near the towns of Des Moines, Cedar Rapids, Sioux City, and Council Bluffs. This rock is said to be very hard and wheel-resisting. It is personally unknown to me, but the reports concerning it indicate that it may have a high value.

Where, as is not infrequently the case, the limestones of this valley, especially those of Carboniferous age, contain segregations of chert which are left on the surface as the lime leaches away, the deposits of this flinty material are often considerable in amount and may have a decided value for roadmaking.

By far the greater part of the Mississippi Valley to the north of the Ohio and the Missouri is deeply covered by deposits of detritus which

were brought into position by the glacier of the last ice epoch. The greater part of this material is of a clayey nature, or is composed of other fragments too fine for use in road construction; and this sheet makes the lower-lying hard rock inaccessible. In the greater part of the prairie district and in much of the timbered country to the east the limestones and other rocks which might serve for roadmaking are accessible only by shafts and would have to be won by deliberate mining, a process which is too costly to be thought of.

Fortunately, while the drift makes access to the bed-rocks impossible, it affords in itself, in the most of the fields where it is found, an abundance of pebbly waste in the form of naturally washed gravels, or in a state where the fragments are commingled with clay under conditions which make it possible to win the pebbles by a simple washing process. In some cases the naturally washed gravels have, on account of the presence of iron or of lime, a sufficient binding quality to make them serviceable in roadmaking without further treatment; in other cases it will be necessary to use only the larger pebbles, say those of an inch or more in diameter, first preparing them for use by a breaking process. As these gravelly materials, especially those which have been washed free of clay, must be the first resort of the roadmakers in this part of the country, I have sought from Mr. Frank Leverett, of the U. S. Geological Survey, the results of his extensive explorations in the States of Illinois, Indiana, and Ohio. As Mr. Leverett has been engaged in a careful study of the drift deposits in these and other States in the West, the information which he has to give is of peculiar value.

As regards the gravel deposits of Illinois, Mr. Leverett furnishes the following statements:

Gravel is sufficiently abundant for roads in the following-named counties: McHenry, Kane, Dupage, northwestern Will, and northern Kendall, where it appears usually in the form of knolls, associated with the moraine. In the northern portion of Ogle County there are a long esker and several knolls which afford that portion of the county plenty of road material. In the eastern part of Winnebago County the glacial terrace along Rock River affords an abundance of gravel. Aside from this limited area Illinois is poorly supplied with gravel. There are, however, in nearly every county within the bounds of the Shelbyville moraine gravelly knolls, either associated with the moraine or on the intermorainic tracts, which furnish gravel for road purposes for the townships in which they happen to occur. There are also small amounts of gravel along the Wabash near the southeastern boundary, on the Embarras in Cumberland, Jasper, and Lawrence counties, and along the Illinois in Peoria, Fulton, Tazewell, and Mason counties.

Indiana is particularly fortunate in its supply of gravel. Nearly every county north of a line passing through Parke, Putnam, Morgan, Johnson, Bartholomew, Decatur, and Franklin counties has gravel conveniently placed for use on its roads.

In Ohio the boundary of the district in which gravel is abundant and extensively used is as follows: On the north, Van Wert, Putnam, Hancock, Seneca, and Huron counties; on the east, Richland, Knox, Licking, and Fairfield counties; and on the south, Ross, Highland, Clinton, Warren, and Butler counties. At a few other points

in Ohio gravel is sufficiently abundant for roads, especially in the interlobate moraine in Stark, Summit, and Portage counties, and in the moraine extending from east to west through the southern parts of Wayne and Ashland counties and the northern part of Holmes County. Gravel is also abundant along the headwaters of the Muskingum, which flows south from the glaciated district. It is less abundant along the banks of the Ohio River, though deposits are not rare along that stream.

In northwestern Pennsylvania there is not much gravel except in the lowlands, but these lowlands afford an inexhaustible supply, so distributed as to make it readily accessible to much of the upland country.

In addition to the foregoing statements of Mr. Leverett it would be well to note the fact that all the streams flowing from the glaciated district southward beyond the boundaries of that field contain, in practically all cases, quantities of gravel in their beds, and there are generally large amounts of the material beneath the alluvial plains on either side of the river beds. It should be observed, however, that in all cases the gravel of the terraces which border the streams is covered over by a deposit of finer materials, so that the pebbly matter is revealed only by excavation, either that effected by the stream in its swayings to and fro or that made artificially.

The deposits of gravel along the channels flowing from the glacial belt are continued as far as the junction of the Ohio and Mississippi rivers, and may, on search, be found along the main streams. The tributaries which enter the Ohio from the south, flowing from a region which was not overlain by the ice, do not afford such gravelly deposits. South and west of the Kanawha River the ice-sheet passed south of the Ohio at only one point, viz, at Cincinnati, where it extended for a mile or two into Kentucky. The result is that the gravels found along the margin of the river lie mostly on its northern side.

In the section between Cincinnati and Louisville there are occasionally beds of course gravel lying in the terraces at considerable heights above the level to which the waters of that stream at present attain. These accumulations were formed before the last glacial period. They are generally firmly cemented by lime, and the greater portions of the included fragments are of limestone. It is uncertain whether these ancient pebbly beds have any value as sources of road materials.

In closing this general account of the roadbuilding materials of the Mississippi Valley it may be well to note the fact that no other part of the United States so much needs a careful study of its materials fitted for highway construction as this extensive and fertile district. The annual tax which poor roads impose upon the agriculture of this field is a very serious hindrance to the welfare of its people. We can not expect it to be lightened except by the collection and dissemination of knowledge concerning the distribution and structure of those rocks which may prove serviceable to the roadmaster.

In the region within the basin of the Great Lakes the problems of highway building are made the simpler by the cheapness with which suitable materials may be conveyed by water transportation. In the

northern peninsula of Michigan and the neighboring parts of Wisconsin and Minnesota there is a great amount and variety of good roadbuilding stones. In fact, no other portion of the continent, so far as known, has within a like area a better supply of such materials. These can be carried at comparatively small cost to all the shore lands of the Great Lakes system. When the canal from Chicago to the Mississippi now under construction is completed, it is probable that the trappean rocks and the low-grade but hard iron ores of the Lake Superior district will be transported to many points on the Mississippi River system.

From Prof. C. R. Van Hise, of the U. S. Geological Survey, I have the following statements concerning the roadbuilding materials of Wisconsin. As the remarks apply to several other States about the Great Lakes which may draw their roadbuilding material from Wisconsin, I shall give them without abbreviation:

The geological formations from which road material is drawn are the pre-Cambrian crystalline rocks and the Lower Magnesian, Trenton, Galena, and Niagara limestones.

In the large Archean areas of the north there is an indefinite supply of crystalline road material, but on account of the expensive transportion little material is drawn from this source, the only locality of which I know being Pike, on the Marquette and Northern Railway. Here a large amount of granite is quarried and shaped into paving stones.

The outcrops of pre-Cambrian in the Paleozoic areas to the south are more largely used. The positions of these isolated masses are indicated by the State Geological Atlas of Wisconsin. The latest description of them is in the Tenth Census, Vol. X, Building Stones, pp. 234–244. This account is mostly compiled from Irving's Wisconsin report. Some of the more important localities are as follows: Montello, which furnishes a considerable quantity of granite for block pavement; Moundville, which furnishes quartz-porphyry for a similar purpose. Quarries have also been opened in the Marcellon quartz-porphyry, in the Marquette quartz-porphyry, in the Berlin granite-porphyry, and in the Mukwa granite, but I do not know that these haye been used for roadbuilding. However, for macadam purposes the most important crystalline rocks are the quartzites of Baraboo and Waterloo. Because of its brittle character this material is readily broken up into all grades of macadam material, and is extensively used in cities as a top dressing to limestone macadam. The combination makes a very durable street. The Waterloo quartzite is also cut into block paving stone.

The cheapest source of macadam for the common roads is the limestone. While the Magnesian, Galena, and Trenton limestones in many places are not adapted for building stones, they are always hard enough to furnish a good macadam, which will wear for many years except for heavy street traffic. The distribution of these limestones ean readily be seen from Chamberlin's general geological map of the State. Wherever there are cities upon or near these limestone formations, those deposits are drawn upon for macadam purposes.

As yet, however, macadam has been very little or not at all used for country roads. In some places the roads extending into the country from cities are macadamized for a greater or lesser distance. The standard material for dressing the country roads is glacial gravel, which in many localities is of a medium degree of coarseness. This material, when intelligently used (but this is not often), makes a very fair country road.

CORDILLERAN DISTRICT.

In general, the amount of energy which has to be expended on the highways of a country, whether in constructing or maintaining the ways or in conveyance over them, is proportionate to the measure of topographic relief which exists there. In a region of great heights the possible roads between points which need to be connected are necessarily much longer than those in the plains. It is true that in the fertile prairies the division of the land into square pieces for purposes of sale has led to the general use of zigzag ways which follow the boundaries of farms, so that the roads on the fertile plains of this country are much longer than is necessary. In a mountain district the length is enforced by the need of placing the way through the meandering valleys. Moreover, the cost of constructing and maintaining a good road on steep grades, such as are inevitably encountered in regions of mountainous relief, is necessarily much larger than on level lands. It may in general be estimated as twice as great. On these accounts the highway problems of the Cordilleran district are of great moment.

There is yet another set of reasons why all matters relating to roads in the high country in the western part of the United States need immediate attention. On account of the peculiarities of soil and of mineral stores, the industries of that region are in a position where their effective development demands a large amount of transportation. The fertile areas are interspersed among the sterile lands, while the under-earth resources are generally placed at a distance from tillable lands. The result is that the mineral stores have, in most cases, to receive a large amount of carriage before they are brought to market, while the miners have to be supplied with food and other necessities by means of an extended transportation. In a word, it costs more in the way of carriage to do business in the Cordilleras than in any other part of this country. It is therefore of the utmost importance that the burden of the road tax should be made as small as possible.

Although we now have a tolerably good knowledge of the geological structure exhibited in the country between the eastern face of the Rocky Mountains and the western shore of the continent, the detailed structure of the region has only here and there been worked out. As the geologists who have done this arduous work have been pioneers in the field, working generally far in advance of civilization, they have naturally paid little attention to the rocks which may be made useful in road-building. In fact, all such matters have only recently come to have an important place in the minds of those who study the resources of the earth. I have personally seen but a small part of the Cordilleran district, and have to confess that, in common with the other men of my craft, I have paid but little attention to the road materials of the fields which I have studied.

The reports and maps of the Cordilleran district show, in a general

way, yet clearly, that the region contains numerous localities of lavas and dikestones which are well fitted for use in road construction. It will be impossible in the space of this report to note the position of these or other suitable materials, but a reference to the general geological map prepared by the U. S. Geological Survey will, to a certain extent, show the reader the positions of the large fields of igneous rock. The innumerable dikes and other possible sources of supply of rock for road construction will be indicated on the detailed maps which the Survey is now preparing.

As is the case with all great mountain systems where in the process of upheaval and erosion the newer rocks are extensively worn away and the older revealed, the Cordilleras exhibit a great many districts of crystalline rocks, such as the granites. Where the dikestones and lavas are wanting it is generally possible to obtain these crystalline granitic materials from their bed places, or from the river deposits of gravel or the glacial accumulations of fragmental stone which have been worn from them.

From Mr. George H. Eldridge, of the U. S. Geological Survey, I have some notes concerning the stratified rocks which may serve in road-building in the Cordilleras, the substance of which I shall now give.

Above the crystalline rocks in the eastern portion of the Rocky Mountains, especially in Colorado, there is a tough quartzite, probably of Devonian age, which has been especially observed in the vicinity of Manitou. This rock will serve very well for macadamizing. The Paleozoic limestones of the same region are of an unusually hard character, and therefore of promising nature. Of these the sub-Carboniferous or Blue limestone is extensively distributed, and is probably of the best quality.

There is another quartzite, probably of Triassic age, occurring at the top of the well-known Red Beds which is likely to afford valuable road material. It is already in use in the region about Denver, and has been shipped from that district for considerable distances to the east.

Concerning the road materials of California, I have the following notes from Mr. J. S. Diller, of the U. S. Geological Survey:

The roadbuilding materials of that region, excepting the basalt, granite, and fine stream gravel, are obtained, so far as I have observed, from the limestones, quartz veins, and flinty beds of the Auriferous slate series. This series is composed of small lenticular masses, and is therefore chiefly of local interest as a source of such material as may be used in roadmaking. Nevertheless, the limestones of various ages—Silurian, Devonian, Carboniferous, Triassic, and Jurassic—are arranged in interrupted belts which can be traced for considerable distances, and occasionally occur in large masses near the railway, so as to be available for transportation. This is true of the Devonian limestone 3 miles southwest of Gazelle, in Siskiyou County, and the Triassic limestones on the stage road to Big Valley, about 40 miles northeast of Redding.

In northern California the large masses of granite and diorite are, in most instances, not conveniently located for transportation, like that of middle California, near Rocklin, on the Central Pacific Railroad, but the long lava-flow which has followed

for 50 miles down the canyon of the Sacramento River lies all the way near the railroad and could supply a large demand.

The siliceous slates of Golden Gate Park are used in San Francisco; but nowhere else, so far as I have seen, is material of any kind extensively employed in macadamizing.

It will be observed that the statements made in this report concerning the stones suitable for roadbuilding which occur in the Cordilleran district are more limited in quantity and value than those given for any other considerable portion of the United States. In this presentation, as elsewhere in the report, it has seemed best to limit the statements to the few facts which have been fairly well established. It is important that by this and other writings roadmasters should not be led to the trial of rocks which, although they on slight inspection appear suitable for roadbuilding, have not been properly essayed. It is evidently better to await the extension of the Survey work over this field, combined with proper experimental tests of the materials, than to risk conjectures as to their value.

REVIEW AND CONCLUSIONS.

So far as the imperfect knowledge now in hand permits the observer to make any general conclusions concerning the condition of the highway problem in this country, we will now endeavor to present them to the reader.

It should in the first place be noted that the larger part of the United States is characterized by great seasonal variations in those climatal features which most affect the conditions of carriage roads. There is prevailingly an alternation of heavy rainfall and protracted drought. In times of rain the roads are subjected to a deep penetration of water and serious washings. In the dry seasons the upper surface becomes powdery and resistant to wheels, and either blows away or is brought into the condition of mud when the ground is wetted. These conditions make high-grade roads peculiarly necessary, but also make their maintenance costly.

Another climatal feature, namely, the great range of temperature, is a considerable disadvantage to our roads. Beneath unimproved ways a deep bed of frozen ground is formed in winter, or perhaps repeatedly formed, and during the period when the frost is coming out, which often lasts some weeks, such unpaved roads are generally unfit for use. It often happens, particularly in the prairie States, that road transportation is nearly impossible for from thirty to sixty days in the spring season. Even on the paved ways the range in temperature, which in the pavement may often amount to nearly 150°, brings about an expansion and contraction which tend to weaken and even to break up the road.

Another disadvantage to be encountered in the effort to improve the condition of our roads arises from the fact that nearly half the area of